AD

USAAVLABS TECHNICAL REPORT 65-55

A STUDY OF REQUIREMENTS FOR ENGINE FAILURE PROTECTIVE WARNING SYSTEMS IN SINGLE-ENGINE TURBINE HELICOPTERS

By

Lawrence A. Kaufman
James L. Van Train

November 1965

U. S. ARMY AVIATION MATERIEL LABORATORIES

FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-155(T)

KAMAN AIRCRAFT CORPORATION

DEPARTMENT OF THE ARMY
U S ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA 23604

This report has been reviewed by the U.S. Army Aviation Materiel Laboratories and is considered to be technically sound. The report is published for the exchange of information and the stimulation of ideas.

Task 1P121401A14178
Contract DA 44-177-AMC-155(T)
USAAVLABS Technical Report 65-55
November 1965

A STUDY OF REQUIREMENTS FOR ENGINE FAILURE PROTECTIVE WARNING SYSTEMS IN SINGLE-ENGINE TURBINE HELICOPTERS

Kaman Report No. R-565

by

Lawrence A. Kaufman
James L. Van Train

Prepared By

Kaman Aircraft Corporation
Electronic Systems Division
Bloomfield, Connecticut

for

U.S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

SUMMARY

With the increased application of gas turbine engines to helicopters, problems have arisen in recovery following engine failure. The source of these problems appears to be the loss of the clear noise level change previously provided in piston engines as an indication of incipient power failure. The result is that the pilot may not be aware that a power failure has occurred until after the rotor speed has decayed below the allowable lower limit.

The purpose of the study reported here is to evaluate the recovery techniques associated with loss of power in single-engine helicopters throughout the flight envelopes currently attainable in actual Army missions. Knowledge of these techniques can then lead, in turn, to the requirements for a protective system designed to assist the pilot after engine failure has occurred.

This study finds, in a probabilistic sense, that the contemplated Army missions for single-engine helicopters require operation in three flight envelopes involving widely varying recovery techniques. This makes the design of a simple automatic collective pitch system virtually impossible. It is also found that with reliable and effective power failure indication, there is ample time for the pilot to effect an orderly manual recovery provided that failure indication is prompt (probably requiring transmittal of the warning indication by means of more than one sense stimulation).

The report includes detailed mission profile analyses, helicopter dynamic analysis and considerations of system design factors to form the background for the results and conclusions that are generated.

FOREWORD

This document represents the final report for a study of requirements for engine failure protective warning systems in single-engine turbine helicopters. The report includes detailed mission profile analyses, helicopter dynamic analysis, and consideration of system design factors. Conclusions and recommendations are presented, predicted upon the information derived during the study program.

The program was conducted by the Electronic Systems Division of Kaman Aircraft Corporation for the U.S. Army Aviation Materiel Laboratories (USAAVLABS), R. P. McKinnon, Contracting Officer. The program was conducted, and this report prepared, by L. A. Kaufman, General Manager, and J. L. Van Train, Project Engineer.

The program was initiated 1 June 1964, under contract DA 44-177 AMC-155(T).

Special acknowledgement for technical support is made to personnel of the following organizations: USAAVLABS, Fort Eustis, Virginia; Combat Development Agency Aviation Branch, Fort Rucker, Alabama; Allison Division of General Motors, Indianapolis, Indiana; Continental Aviation, Detroit, Michigan; and Lycoming Division of AVCO, Stratford, Connecticut.

CONTENTS

ILLUSTRATIONS

SYMBOLS

F_{x_q} Helicopter forward force due to change in rate of pitch - pounds/radian/second

F_{x_u} Helicopter forward force due to change in forward velocity - pounds/foot/second

F_{x_w} Helicopter forward force due to change in vertical velocity - pounds/foot/second

$F_{x_{\delta_0}}$ Helicopter forward force due to change in collective stick position - pounds/radian

$F_{x_{\delta_1}}$ Helicopter forward force due to change in longitudinal cyclic stick position - pounds/radian

F_{x_θ} Helicopter forward force due to change in pitch attitude - pounds/radian

F_{x_Ω} Helicopter forward force due to change in rotor speed - pounds/radian/second

F_{z_q} Helicopter vertical force due to change in rate of pitch - pounds/radian/second

F_{z_u} Helicopter vertical force due to change in forward velocity - pounds/foot/second

F_{z_w} Helicopter vertical force due to change in vertical velocity - pounds/foot/second

$F_{z_{\delta_0}}$ Helicopter vertical force due to change in collective stick position - pounds/radian

$F_{z_{\delta_1}}$ Helicopter vertical force due to change in longitudinal cyclic stick position - pounds/radian

F_{z_θ} Helicopter vertical force due to change in pitch attitude - pounds/radian

F_{z_Ω} Helicopter vertical force due to change in rotor speed - pounds/radian/second

h_n Aircraft Altitude at time $t = t_n$ - feet

h_{n-1}	Aircraft altitude at time $t = t_{n-1}$ - feet
I_s	Mass moment of inertia of rotor about the spin axis - slug-feet
I_y	Mass moment of inertia of helicopter about the pitch axis - slug-feet
M_q	Helicopter pitching moment due to change in rate of pitch - foot-pounds/radian/second
M_U	Helicopter pitching moment due to change in forward velocity - foot-pounds/foot/second
M_w	Helicopter pitching moment due to change in vertical velocity - foot-pounds/foot/second
M_{δ_0}	Helicopter pitching moment due to change in collective stick position - foot-pounds/radian
M_{δ_1}	Helicopter pitching moment due to change in longitudinal cyclic stick position - foot-pounds/radian
M_θ	Helicopter pitching moment due to change in pitch attitude - foot-pounds/radian
M_Ω	Helicopter pitching moment due to change in rotor speed - foot-pounds/radian/second
m	Mass of helicopter - slugs
N_2	Angular velocity of turbine output shaft - r.p.m.
q	Helicopter angular velocity about pitch axis - radians/second
$\dot{q}$	Helicopter angular acceleration about pitch axis - radians/second/second
Q_E	Rotor shaft torque at time of simulated power failure - foot-pounds
Q_q	Rotor shaft torque due to change in rate of pitch - foot-pounds/radian/second

Q_U	Rotor shaft torque due to change in forward velocity - foot-pounds/foot/second
Q_w	Rotor shaft torque due to change in vertical velocity - foot-pounds/foot/second
Q_{δ_0}	Rotor shaft torque due to change in collective stick position - foot-pounds/radian
Q_{δ_1}	Rotor shaft torque due to change in longitudinal cyclic stick position - foot-pounds/radian
Q_θ	Rotor shaft torque due to change in pitch attitude - foot-pounds/radian
Q_Ω	Rotor shaft torque due to change in rotor speed - foot-pounds/radian/second
t_n	Elapsed time, following takeoff, at the termination of the time period under consideration for the determination of the takeoff/landing flight profile - seconds
t_{n-1}	Elapsed time, following takeoff, at the initiation of the time period under consideration for the determination of the takeoff/landing flight profile - seconds
U	Helicopter forward velocity - feet/second
$\dot{U}$	Helicopter forward acceleration - feet/second/second
u_n	Helicopter forward velocity at time $t = t_n$ - feet/second or knots
u_{n-1}	Helicopter forward velocity at time $t = t_{n-1}$ - feet/second or knots
w	Helicopter vertical velocity - feet/second
$\dot{w}$	Helicopter vertical acceleration - feet/second/second
w_n	Vertical velocity at time $t = t_n$ - feet/second
w_{n-1}	Vertical velocity at time $t = t_{n-1}$ - feet/second
$\ddot{X}$	Average forward acceleration - g's

$\ddot{z}$	Average vertical acceleration above or below 1g - g's
Δ	Increment of
δ_0	Collective stick position - radians
δ_1	Longitudinal cyclic stick position - radians
δ_f	Final Collective Stick position - radians
θ	Helicopter pitch attitude - radians
τ	Rotor speed decay time constant - seconds
T	Delay time before actuation of collective stick - seconds
Ω	Rotor speed - radians/second
$\frac{d\delta}{dt}$	Rate of change of collective stick position - radians/second

BLANK PAGE

INTRODUCTION

This program is concerned with the incorporation of a protective device in single turbine engine helicopters which operates in the event of engine failure. The requirement for this study has developed because the noise cue (heretofore available in piston engine aircraft) no longer provides clear indication of incipient power failure. Without this intrinsic warning cue, valuable time may be lost in recognition of the failure condition, thereby denying the possibility of a safe recovery.

The solution to the problem is a device which, in its most complex, fully-automatic form, would contain three major elements: an engine failure detector, a computer to determine appropriate collective pitch action, and an actuator to change collective pitch setting in accordance with the computer output. The need for each of the above mentioned elements, and the extent to which each may be needed, is based on the following major considerations:

1. What kind of recovery techniques are required as a function of typical usage of Army helicopters? (This leads to considerations of mission profiles.)

2. What is the consequence of an engine failure in the sense of required response? Do events (following failure) occur too fast to rely on pilot response or is there adequate time available, provided that the failure is promptly and accurately recognized?

The general approach followed in developing answers to these questions is as follows:

1. A mission profile analysis is carried out to determine the major velocity-altitude domains in which the helicopter is normally operated. This is ultimately reduced to an expression of the percentage of operating time that may be anticipated to pertain to each of four major flight envelopes. The recovery technique corresponding to each flight envelope is described functionally.

2. Dynamic analysis and flight test data are used to determine the effects of engine failure followed by various recovery techniques. The UH-1 and UH-2 helicopters are used as models of appropriate single-engine configurations. The results of this study are reduced in terms of the multiple of typical pilot reaction time increments available to effect an orderly recovery. Included in this study are considerations of rotor speed decay, vertical acceleration and pilot reaction time.

These two phases of the analysis of the problem are followed with discussions of system implementation after it is demonstrated that the requirement reduces to the provision of an engine failure detection device.

MISSION PROFILE ANALYSIS

The requirement for a study of Army mission profiles can best be established by consideration of Figure 1. This qualitative figure is a typical height/velocity diagram which permits an interpretation of the immediate collective pitch response requirement following single-engine failure in level flight. The boundaries added to this figure could be assumed to apply to a specific pilot, at a specific value of gross weight, density altitude, center of gravity and wind. With variations in these parameters, and with initial vertical rate unequal to zero, the boundaries shown in Figure 1 would vary.

Despite the essentially qualitative nature of Figure 1, some interesting conclusions may be deduced regarding the nature of the collective pitch response problem following engine failure. These conclusions are essentially independent of specific quantitative boundary locations. It is, therefore, desirable to consider the physical bases for the boundaries of Figure 1.

The crosshatched areas are the typical dead man zone for a single-engine helicopter. By definition, engine failure in these regions will be catastrophic and no collective pitch correction is meaningful. These areas are, therefore, excluded from consideration. Even with the availability of a good protective system, it is unlikely that flight would be undertaken in the dead man zone unless the unique requirements of the mission justify the risk exposure involved.

Area I covers a range of very low altitudes (less than 10 feet) and low airspeed (less than 45 knots). It is an area involved primarily in takeoff and landing. Following engine failure in this flight envelope, the most desirable recovery technique will almost always involve an initial increase of collective pitch. This will be especially true of the low-speed, near-hover boundary. Because of the close proximity of the aircraft to the ground, the increase in collective pitch is needed to attenuate vertical sink rate. The almost negligible time involved to touch down precludes excessive rotor speed decay; rotor speed decay after touchdown is of no consequence.

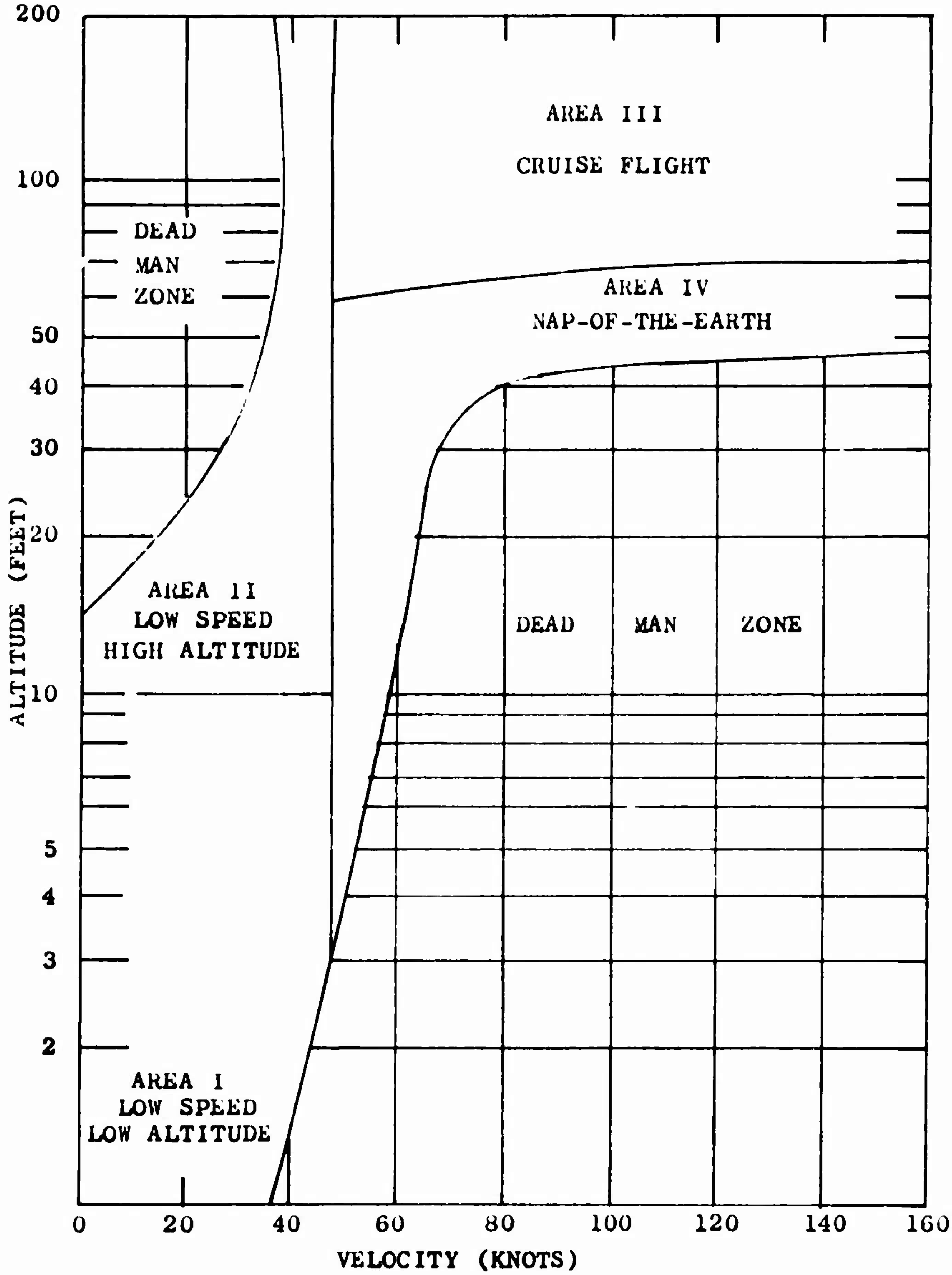


FIGURE I. FLIGHT ENVELOPES.

Area II represents a region of low airspeed (less than 45 knots) and higher altitude (over 10 feet). This area of flight is involved in tactical hovering, or in transition to cruise flight. At the low altitude boundary of the region, recovery after engine failure will probably involve initial increase of collective pitch (as in Area I). At the upper speed and altitude boundaries, the recovery maneuver will involve autorotation. The median portion of the area may involve initially holding the existing collective pitch setting followed by an increase in collective pitch as the aircraft approaches touchdown.

Area III is the normal cruise envelope of the helicopter. The recovery technique involved here will be to establish autorotation. The synchronized pitch attitude maneuver used to accompany the reduction of collective pitch will be to maintain best autorotation speed, usually of the order of 45 knots.

Area IV is characteristic of Army nap-of-the-earth flight, which combines very low altitudes (of the order of less than 100 feet above terrain) and higher airspeeds (above 45 knots). This is the most difficult area in which to recover after engine failure for two reasons. First, this region is continuously adjacent to the high speed portion of the dead man zone. (In fact, a well-planned and executed nap-of-the-earth flight is one in which the aircraft is maintained as close to the dead man zone boundary as possible, thereby minimizing vulnerability to enemy fire.) Second, the aircraft kinetic energy is high, making the energy management problem more critical. Recovery, following engine failure in Area IV, will require a carefully coordinated collective pitch/pitch attitude program. At the low speed, low altitude boundary, the initial collective pitch response could involve increase of collective pitch (that is, as if this were, in fact, the terminal phase of a flare following normal autorotation). As airspeed increases, it will become increasingly more important to preserve rotor speed, thereby entailing an initial decrease in collective pitch.

If the recovery requirements for the four areas are considered together, the following functional conclusions appear:

1. Depending upon the condition of flight, the initial collective pitch response following engine failure covers a range which includes:

    a. Pull it up.

b. Push it down.

c. Leave it alone.

2. As the conditions of flight change (for example, approach rather than level flight), the boundaries shift and the response requirements change.

3. Although no mention has been made of the time response of collective pitch following engine failure, this will vary considerably within the regions sketched; for example, following a loss of engine power at an altitude of 1 foot in hover, although increased collective is the qualitatively correct maneuver, almost any rate is satisfactory and the chances are fairly good that even down collective will not hurt. On the other hand, for high speed flight conditions, more rapid actuation is required following engine failure.

4. The characteristics of the physical problem are nonlinear in nature and it can, therefore, be deduced, that a completely automatic device designed to solve the problem must be capable of making nonlinear calculations.

5. The problem is essentially one of prediction or extrapolation. The strategy employed to recover after an engine failure is based very heavily on what the anticipated consequences of the action will be at some later time.

Since the combined requirements of all four areas of flight are extremely complex, it is logical to first examine the actual operational usage of Army aircraft, to determine the statistical importance of each of the areas of Figure 1. Using mission profile data available from the Combat Development Agency Aviation Branch, Fort Rucker, such an analysis has been carried out for the single-turbine-engine Army aircraft of current interest: LOH, UH-1B and UH-1D.

The analytical technique is described fully in Appendix I. It consists of an account of each stage of each mission as an expression of the time spent in each of the four flight areas of interest. In landing and takeoff sequences, a typical trajectory is employed as illustrated in Figure 2. After accounting for each mission in this way, the importance of each of the missions is established by assignment of weighting factors, chosen to account for the anticipated relative frequency of the various missions.

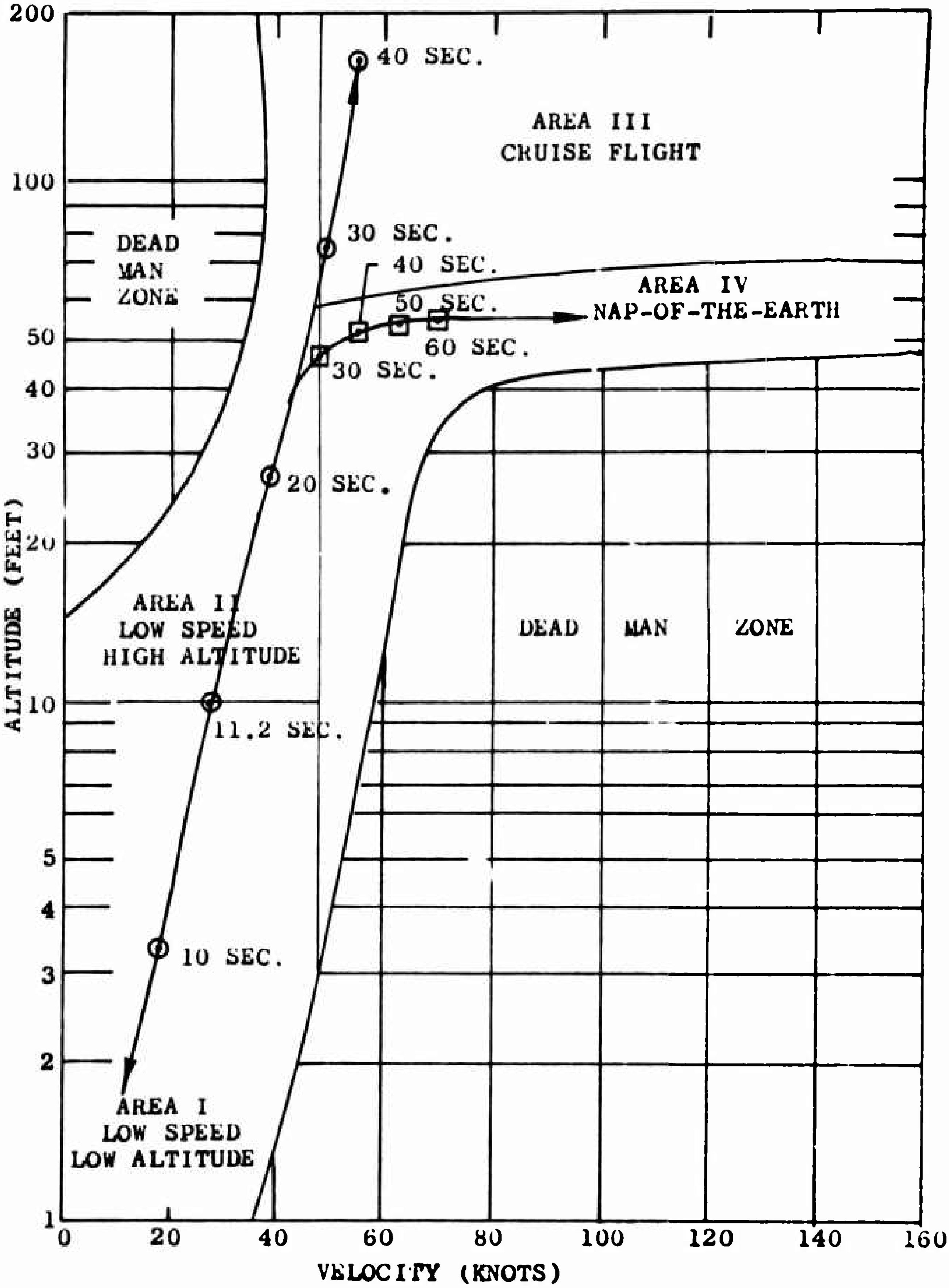


FIGURE 2. TAKEOFF/LANDING TRAJECTORIES.

The results of this analysis for the three aircraft studied are indicated in Table 1.

TABLE 1

MISSION ANALYSIS SUMMARY

Aircraft Type	Average Flight Duration (Hours)	Time Duration in Percent			
		Area I	Area II	Area III	Area IV
LOH	1.46	2.9	9.3	59.8	28.0
UH-1B	2.34	0.3	0.5	17.6	81.6
UH-1D	2.31	0.8	1.9	51.0	46.3

Some interesting conclusions can be derived from the results presented in Table 1. It may be noted that the only flight area which is virtually negligible on a statistical basis, is the low altitude, low speed area, Area I. This flight envelope covers less than 5 percent of all of the tactical flight situations studied here. Further, the aircraft is least vulnerable to crash damage in this flight envelope, since it possesses (relatively) little kinetic and potential energy.

The remaining three flight areas must all be accounted for in the protective system, since none of these areas is statistically negligible. Yet, the recovery requirements in the three areas differ markedly (as described earlier). Therefore, the conclusion that can be drawn on the basis of planned use of Army single-engine helicopters is that a protective system, if required, in its most automatic form, would need to be capable of operation in three areas of flight which collectively embrace a most complex requirement.

The only question requiring resolution now, is whether or not the system must, in fact, be fully automatic. The criterion for this judgement is the response required to recover, compared with the available pilot response. If the required response exceeds pilot response, a complex automatic actuation system must be specified. If the pilot response can be shown to be adequate, the actuation requirements can be deleted.

The purpose of the following section of this report is to type-analyze the response requirement versus the availability capacity. This analysis determines whether a complex or simple system is necessary.

Before proceeding to this section, it is well to emphasize that the results cited in Table 1 are for tactical missions. While nontactical missions have not been treated, they could be expected to cover three general kinds of missions: simulated tactical missions, cross-country missions, and proficiency and training missions. As such, it may be anticipated that they would obey the same general conclusion reached in analysis of tactical flights; that is, that they primarily involve exposure in the three major areas: II, III and IV.

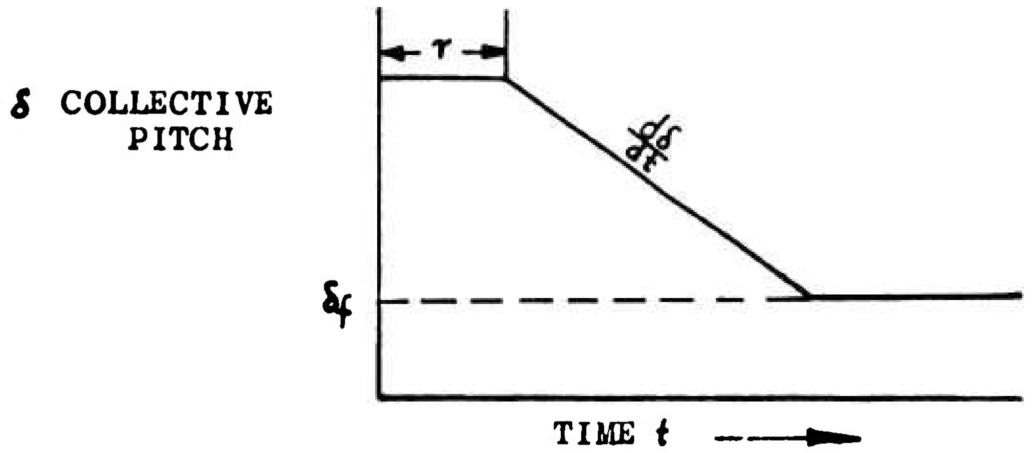
HELICOPTER DYNAMIC ANALYSIS

A parametric dynamic analysis of two helicopters has been conducted to establish the response of the aircraft following a loss of power. Various control inputs have been considered during the course of the study to determine the response that would be required of either a pilot or an automatic actuation system for two typical aircraft.

The two aircraft used in the study are the UH-1 and UH-2. The UH-1 was chosen since it represents the most important single-turbine engine, operational helicopter in the present Army inventory. The UH-2 was chosen by virtue of its marked performance differences relative to the UH-1, thereby ensuring that the conclusions obtained using the UH-1 are not unique. Results of the studies of the two aircraft show a remarkable similarity.

The dynamic analysis of the UH-2 was conducted by using an analog computer simulation of the aircraft. The dynamic analysis of the UH-1 consisted primarily of an examination of flight test data, dealing with an investigation of rotor behavior following throttle chop for the YH-40 helicopter.*

The computer analysis considered the response of the aircraft following engine failure using the collective pitch response shown below.



* R. Wheelock, "Investigation of Rotor Behavior Following Throttle Chop - YH-40 Helicopter", Bell Helicopter Corporation Report No. 204-099-929, July 1959

The three parameters are τ , a dead time lag allowed for recognition of engine failure, $\dot{\delta}$ actuation rate, and δ_f , final collective pitch position. These parameters were varied widely as follows:

τ Zero to five seconds

$\dot{\delta}$ Very small values to infinite slope (step)

δ_f From 0 percent to 100 percent of full stroke available

The aircraft response has been characterized in terms of time histories of the following dependent variables: rotor speed, vertical displacement, vertical rate, vertical acceleration, airspeed, and pitch attitude.

The manner in which the aircraft response was monitored is illustrated in Figure 3. This figure is a copy of a typical time history obtained from the computer simulation of the UH-2. The simulation technique is described in Appendix II. The traces show the form of the collective command (in this case, a 1-second delay followed by a 5-degree-per-second ramp), vertical velocity and acceleration, airspeed, altitude and rotor speed, all as a function of time following loss of power.

One of the most important factors to be considered is the rotor speed response as a function of the control inputs following power failure. Figure 4 shows the peak rotor speed droop as a function of collective pitch actuation delay time and as a function of the rate at which the collective stick is dropped. Data for the curves were obtained from the computer simulation of the UH-2 flying level at 130 knots at a normal gross weight of 7,558 pounds. After power failure and the appropriate time delay, the collective stick was dropped to the full down position.

To interpret the curves of Figure 4, it is necessary to recall the manner in which peak rotor speed droop is measured; that is, as shown in Figure 3. It is apparent that speed droop will increase with increasing delay time and with reduced actuation rate. These relations are evident in Figure 4.

The total response area shown in Figure 4 may be restricted by superposition of three boundaries. The first boundary is the ordinate drawn through the -20 percent rotor-speed-increment. This establishes a minimum rotor speed boundary based on the published 80 percent limit for the UH-2 helicopter. The abscissa boundary of 1-second delay is an estimate of minimum recognition time. This is discussed more fully in a

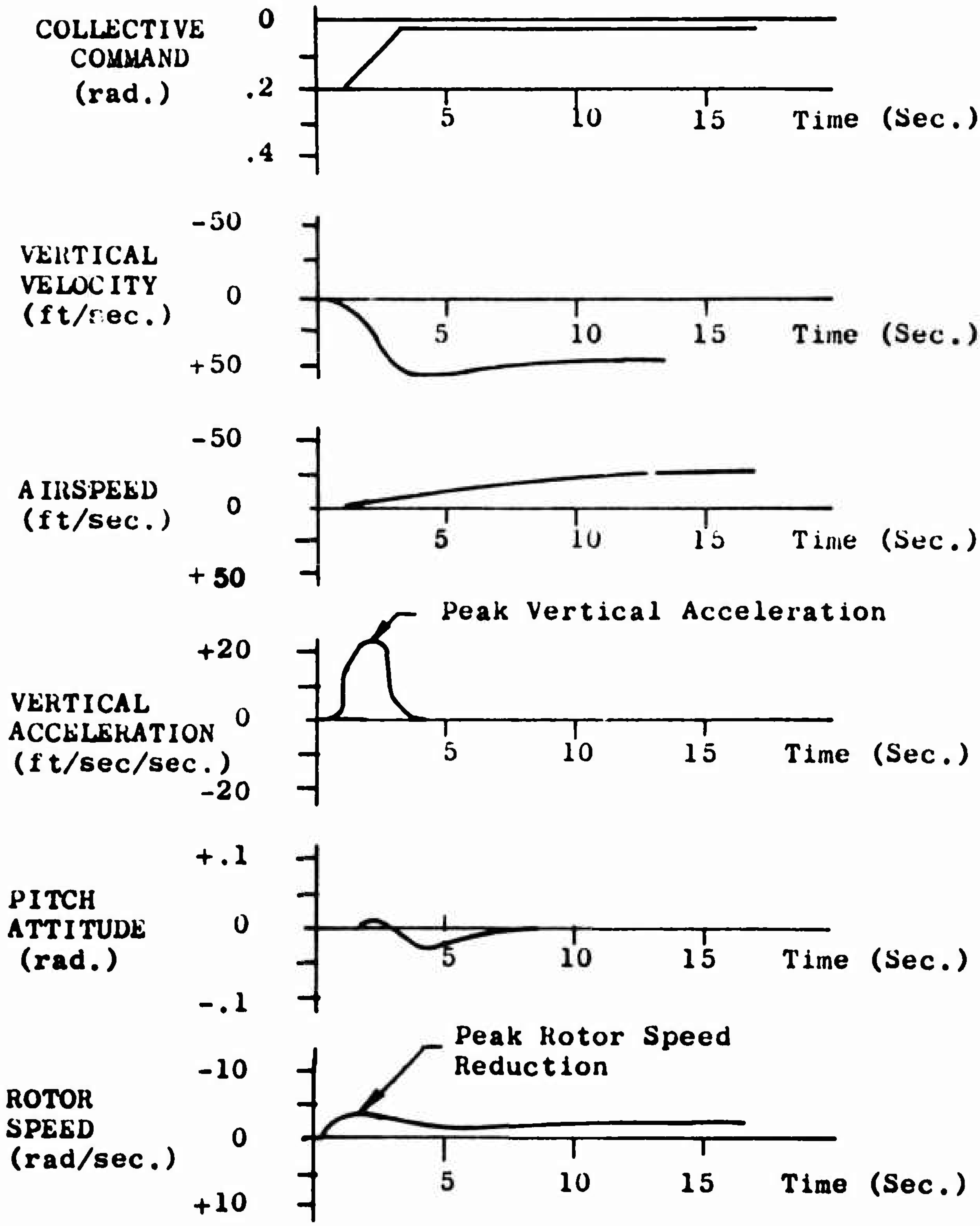


FIGURE 3. TYPICAL TIME RESPONSE, UH-2 COMPUTER SIMULATION, 130 KNOTS, NORMAL GROSS WEIGHT, 1-SECOND DELAY, 5-DEGREES-PER-SECOND RAMP.

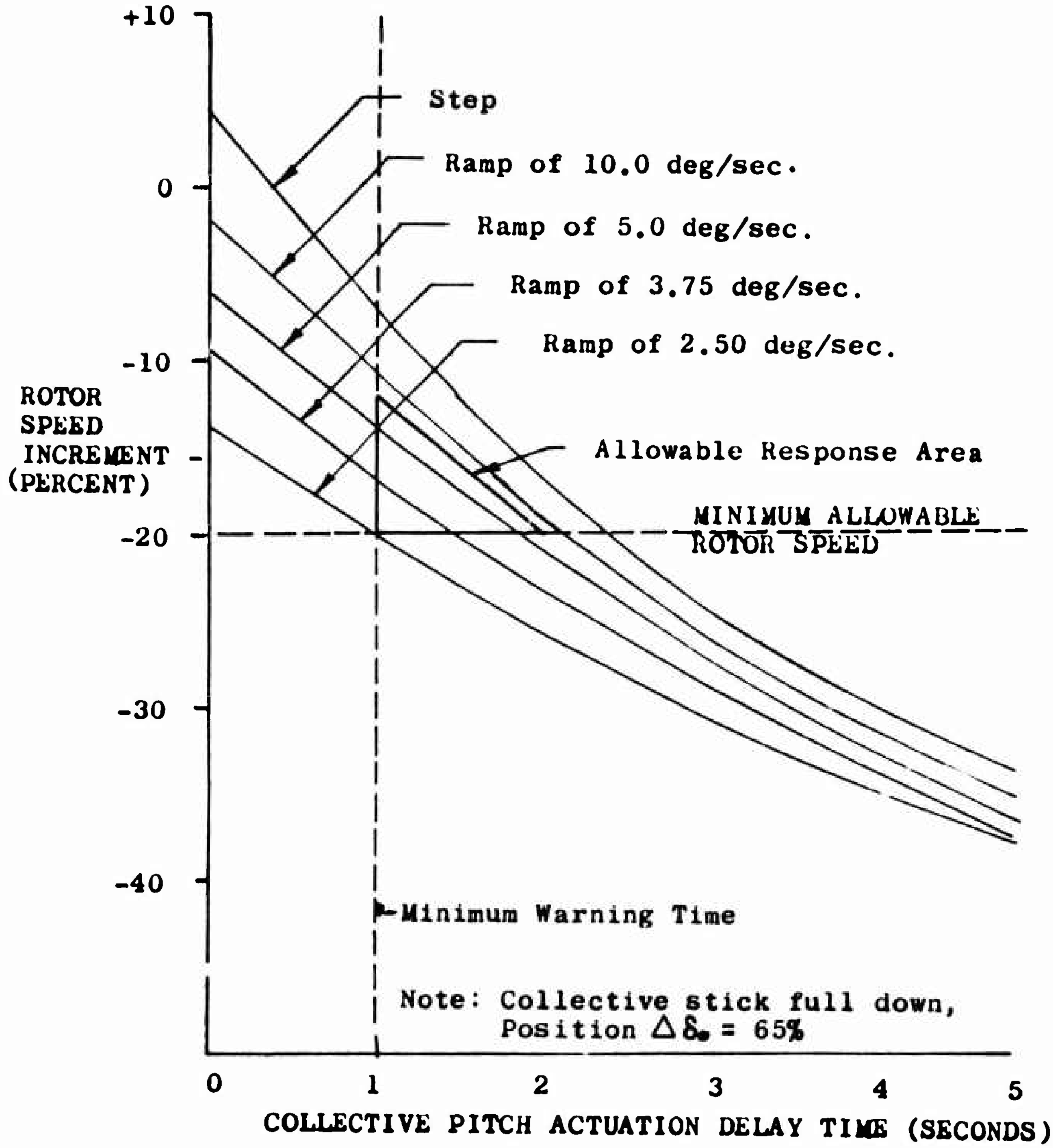


FIGURE 4. UH-2 HELICOPTER, MAXIMUM TRANSIENT ROTOR SPEED INCREMENT AS A FUNCTION OF COLLECTIVE PITCH ACTUATION TIME, 130-KNOT CRUISE.

later section. The boundary is closed by a curve falling between the parametric curves for actuation rates of 5 degrees per second and 10 degrees per second as determined by limitation of vertical acceleration increments to not more than 1 g. downward from level flight. (This relation between actuation rate and vertical acceleration is presented in Figure 5.) This limitation keeps a sufficient margin relative to the structural acceleration limit of -0.5 g. for the aircraft. It also prevents the pilot from being "lifted" from his seat, which would be unacceptable in an automatic actuation system, no matter how brief the interval of time.

Returning to Figure 4, and considering the limits involved, two interesting conclusions may be derived. First, using an actuation rate of 5 degrees per second (well within the pilot response capability and yet far removed from the negative acceleration boundary), the maximum delay which can be tolerated is 2.3 seconds. Thus, if the collective stick is moved to its lower limit at a rate of 5 degrees per second starting 2.3 seconds after engine failure, the rotor speed droop will be held within acceptable limits. Second, assuming that the 1-second minimum recognition time can be substantiated as being reasonable, a margin of 1.3 seconds in time is available. That this margin is reasonable requires correlation to typical pilot reaction time.

Considerable effort has been expended to establish the time required for the pilot to make a proper response to various stimuli. The following definition of reaction time has been excerpted from "The Human Pilot".*

> "Reaction Time is defined to be the time which elapses between the presentation of a stimulus to a subject and the beginning of the response to this stimulus. The subject's response to the stimulus will then be split into two distinct phases: 1) the reaction time, during which no movement is made, and 2) the movement time, itself. If the time required for the subject to make the response following the stimulus is called the response time, then
>
> Response time = Reaction time + Movement time"

* Northrop Aircraft, "The Human Pilot", BU-AER Report AE-61-4 III, August 1954

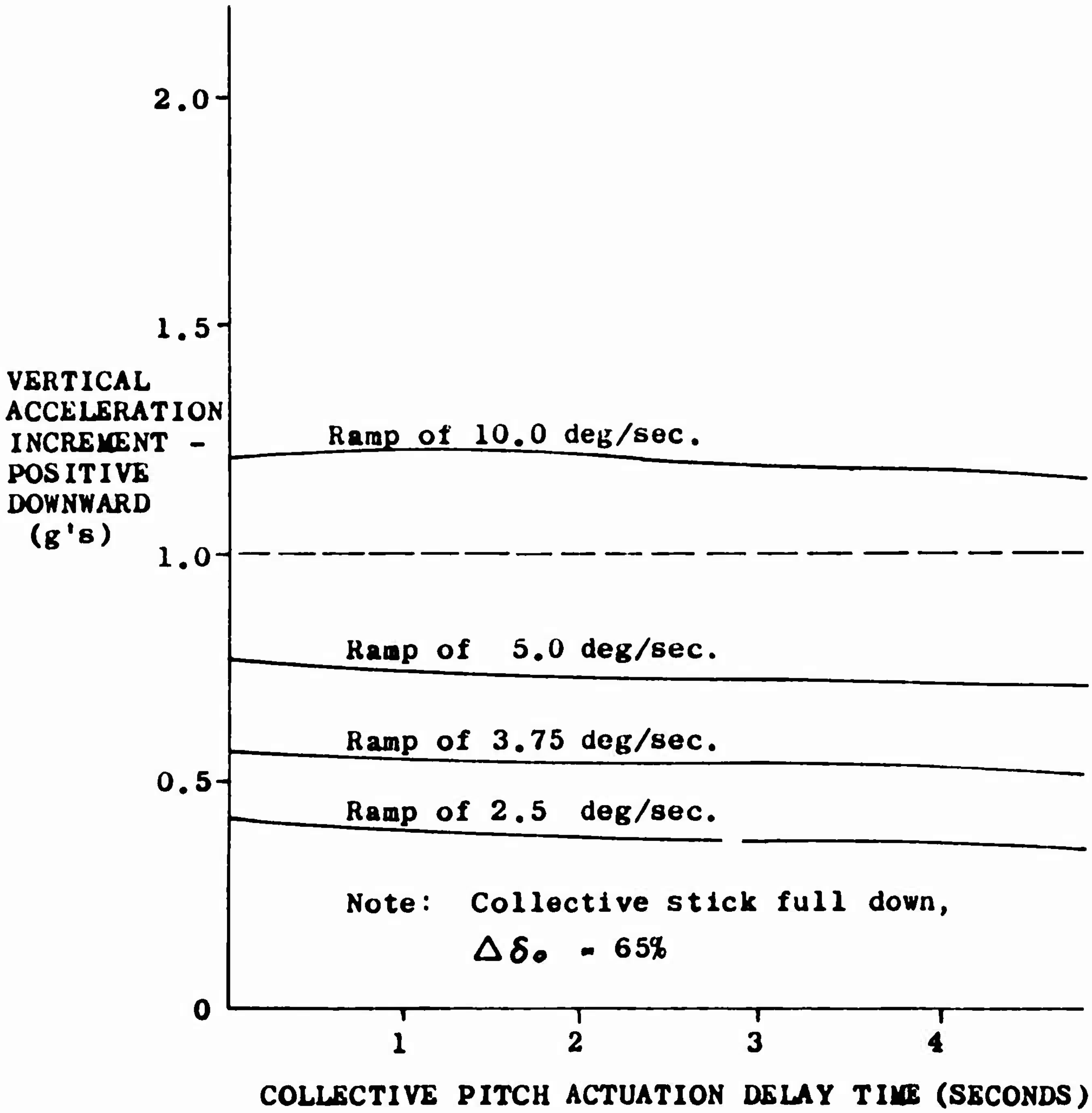


FIGURE 5. UH-2 HELICOPTER, MAXIMUM TRANSIENT VERTICAL ACCELERATION INCREMENT AS A FUNCTION OF COLLECTIVE ACTUATION DELAY TIME, 130-KNOT CRUISE.

To judge the adequacy of the time margin of 1.3 seconds shown in Figure 4, it is necessary to consider the reaction time, since movement time has been allocated separately. Reaction time is dependent upon several factors including the following:

1. The sense which is stimulated. (In the case of the eye, the reaction time depends on which portion of the eye receives the stimulus.)

2. The intensity of the stimulus.

3. Whether or not the subject is given a warning before the stimulus is presented; and if so, the duration of the period between the warning and the stimulus.

4. The effectors used in making the response.

5. Whether the reaction is simple or complex.

Given favorable conditions, the minimum pilot reaction time may be taken to be approximately 0.2 second for a simple reaction. It is apparent, therefore, that the margin of 1.3 seconds allowed for pilot reaction exceeds best pilot reaction capability by a ratio of six to one.

The preceding discussion has been concerned with characteristics of the UH-2 at a comparatively high cruise speed. The rotor speed and vertical acceleration response of the aircraft at hover are given in Figures 6 and 7 respectively. Comparing these two sets of curves with those of Figures 4 and 5, it can be seen that the conclusions drawn from the higher speed studies are equally valid for the hover condition. The time available for the pilot to respond before the rotor speed droop is excessive and is even greater than was the case under cruise conditions.

Rotor speed decay characteristics of the UH-1 are presented in Figure 8. This figure shows the same characteristics for the UH-1 as were shown in Figure 3 for the UH-2. The rotor response shown is for the YH-40, flying at 20, 40, 60 and 80 knots, and at high, normal and low gross weights.* The consistency of the indicated response over this wide range of flight conditions serves to verify that the effect of a

* R. Wheelock, "Investigation of Rotor Behavior Following Throttle Chop - YH-40 Helicopter", Bell Helicopter Corporation, Report No. 204-099-929, July 1959

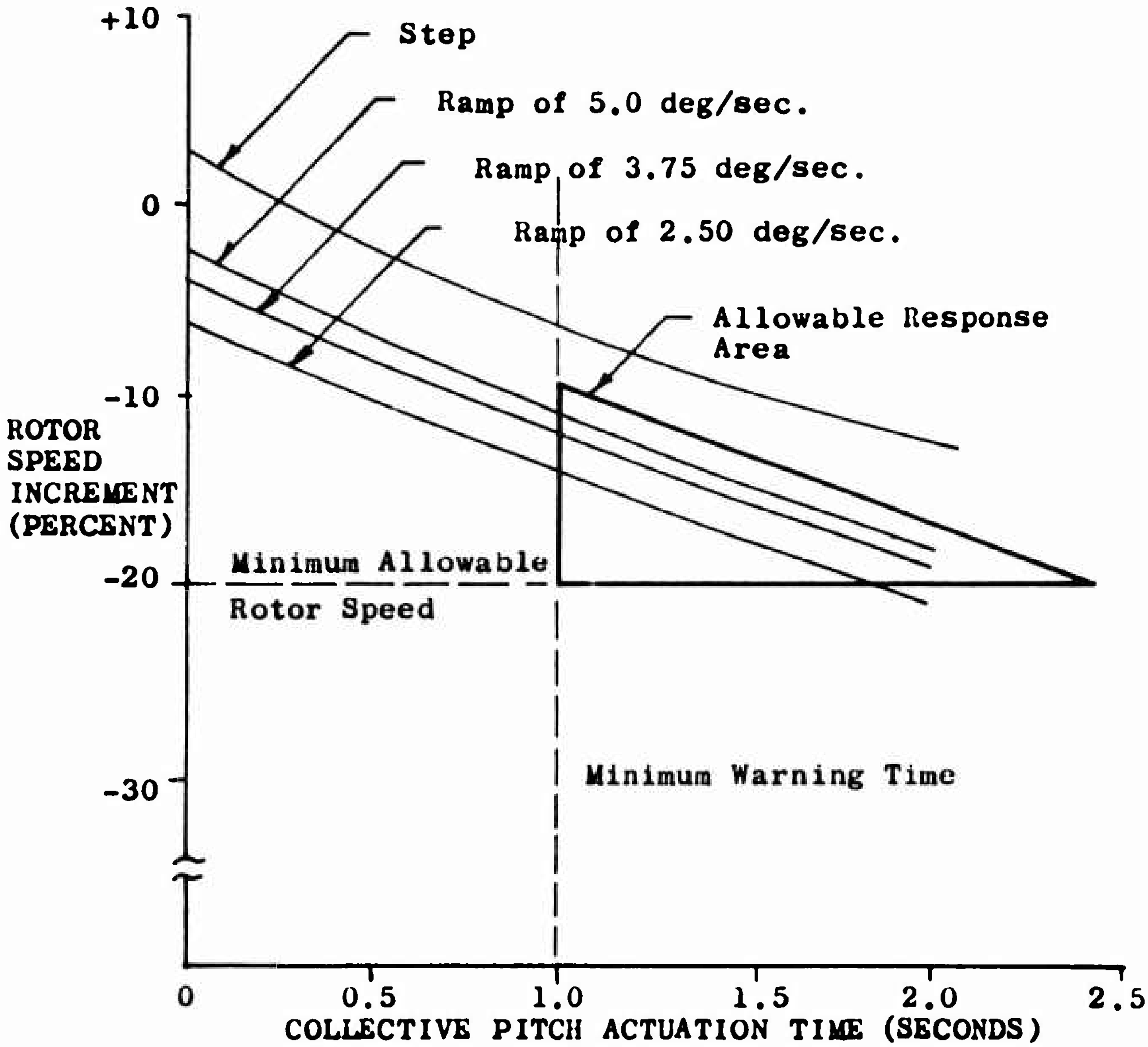


FIGURE 6. UH-2 HELICOPTER, MAXIMUM TRANSIENT ROTOR SPEED INCREMENT AS A FUNCTION OF COLLECTIVE PITCH ACTUATION TIME, HOVER, FULL DOWN COLLECTIVE.

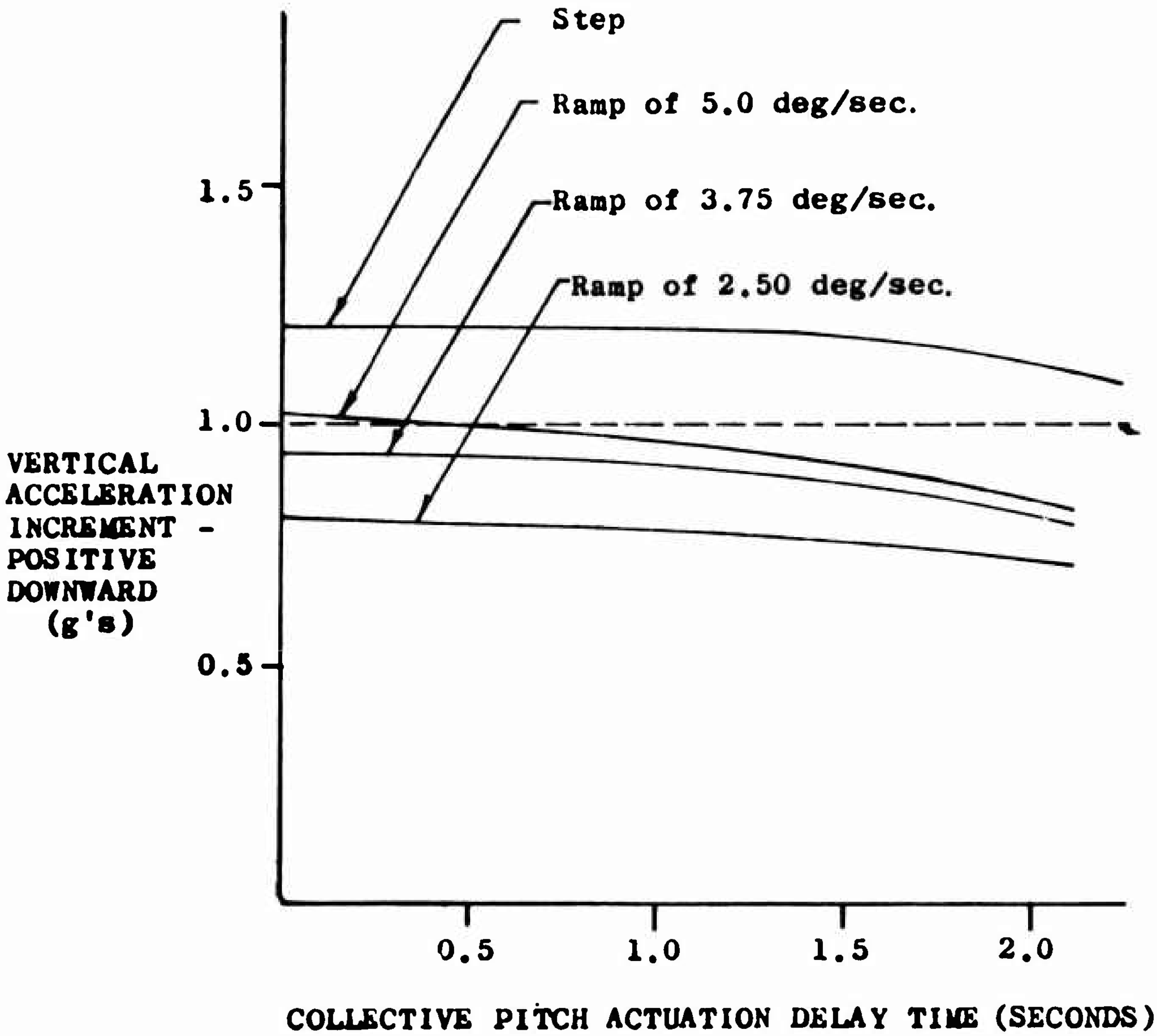


FIGURE 7. UH-2 HELICOPTER, MAXIMUM TRANSIENT VERTICAL ACCELERATION INCREMENT AS A FUNCTION OF COLLECTIVE PITCH ACTUATION DELAY TIME, HOVER, FULL DOWN COLLECTIVE

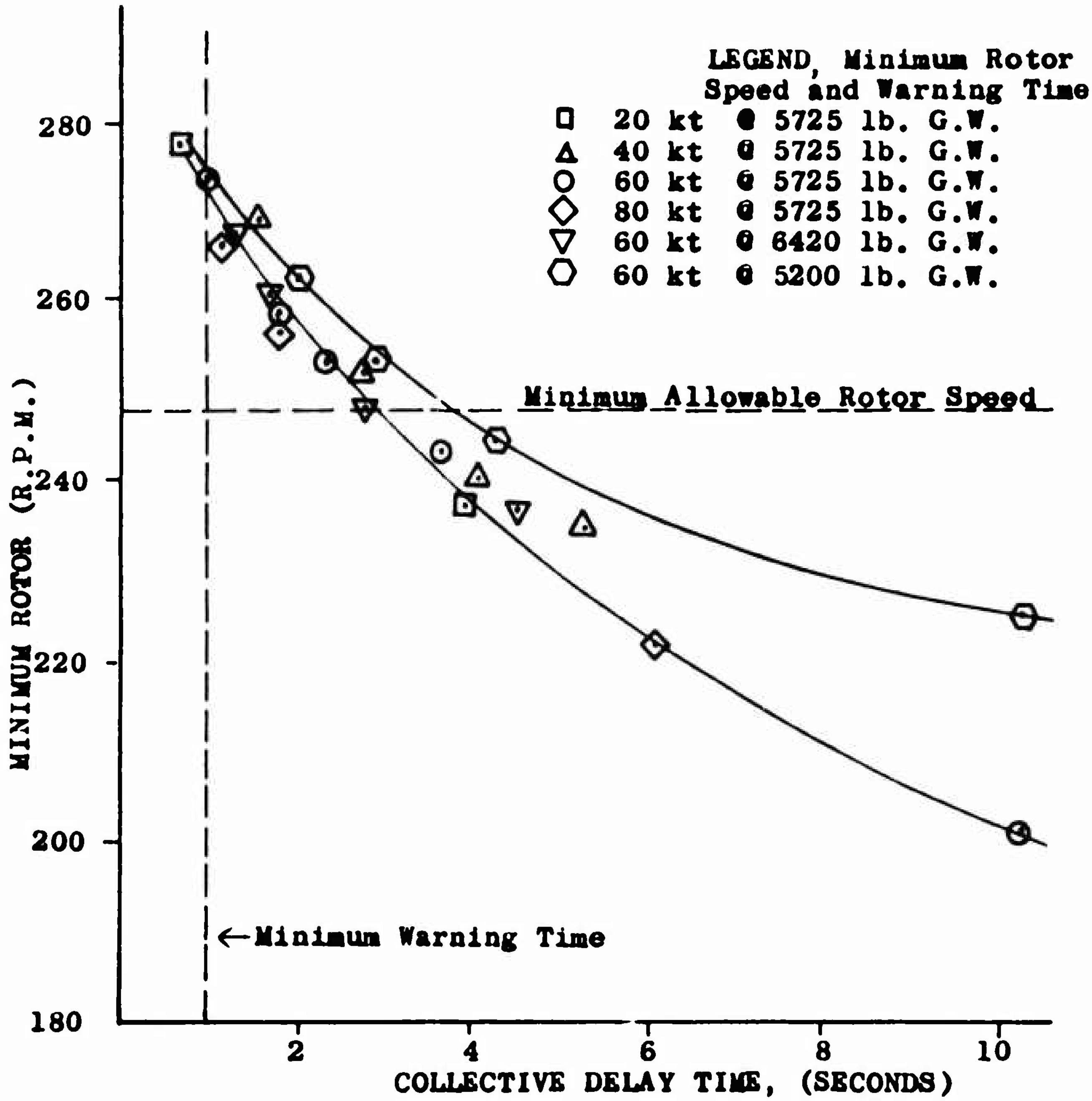


FIGURE 8. ROTOR R.P.M. DECAY VERSUS COLLECTIVE PITCH ACTUATION DELAY TIME, YH-40

power loss on the rotor r.p.m. is affected only slightly by airspeed, at least in the range reported. This conclusion agrees with the results obtained in dynamic analysis of the UH-2 helicopter.

The data of Figure 8 indicate that the maximum delay tolerable to preclude excessive rotor speed decay is about 2.8 seconds - a result quite similar to that obtained in analysis of the UH-2.

The rotor responses for the two aircraft are presented simultaneously in Figure 9, to show the close agreement between the results of the two studies.

The previous discussion has been concerned with restrictions imposed upon the manner in which the pilot may respond to an engine failure as governed by rotor speed droop, downward vertical acceleration, and the time required to confidently indicate a power loss. Another significant restriction concerns itself with the loss of altitude experienced by the aircraft shortly after loss of power. This consideration is extremely important for those cases in which the aircraft is flying at a comparatively low altitude (in Area IV of Figure 1) so that an excessive loss of altitude is obviously more dangerous than the rotor speed and acceleration considerations mentioned previously.

The study of response characteristics of the helicopter models considered here leads to the following results:

1. A delay of the order of 2.3 seconds may be tolerated before effecting collective pitch control following engine failure while still precluding excessive rotor speed decay. This result holds for both the UH-2 and UH-1 helicopters.

2. If engine failure can be detected within the first second following failure, safe recovery should be possible, since over six times the pilot reaction time is available; that is, difference between the time allowed and the 1 second required for failure detection.

3. Since the response demands on the pilot are well within his capacity, the need for automatic actuation vanishes since there is enough time for pilot actuation. The ability to avoid automatic actuation reduces system complexity and, at the same time, should promote pilot acceptance.

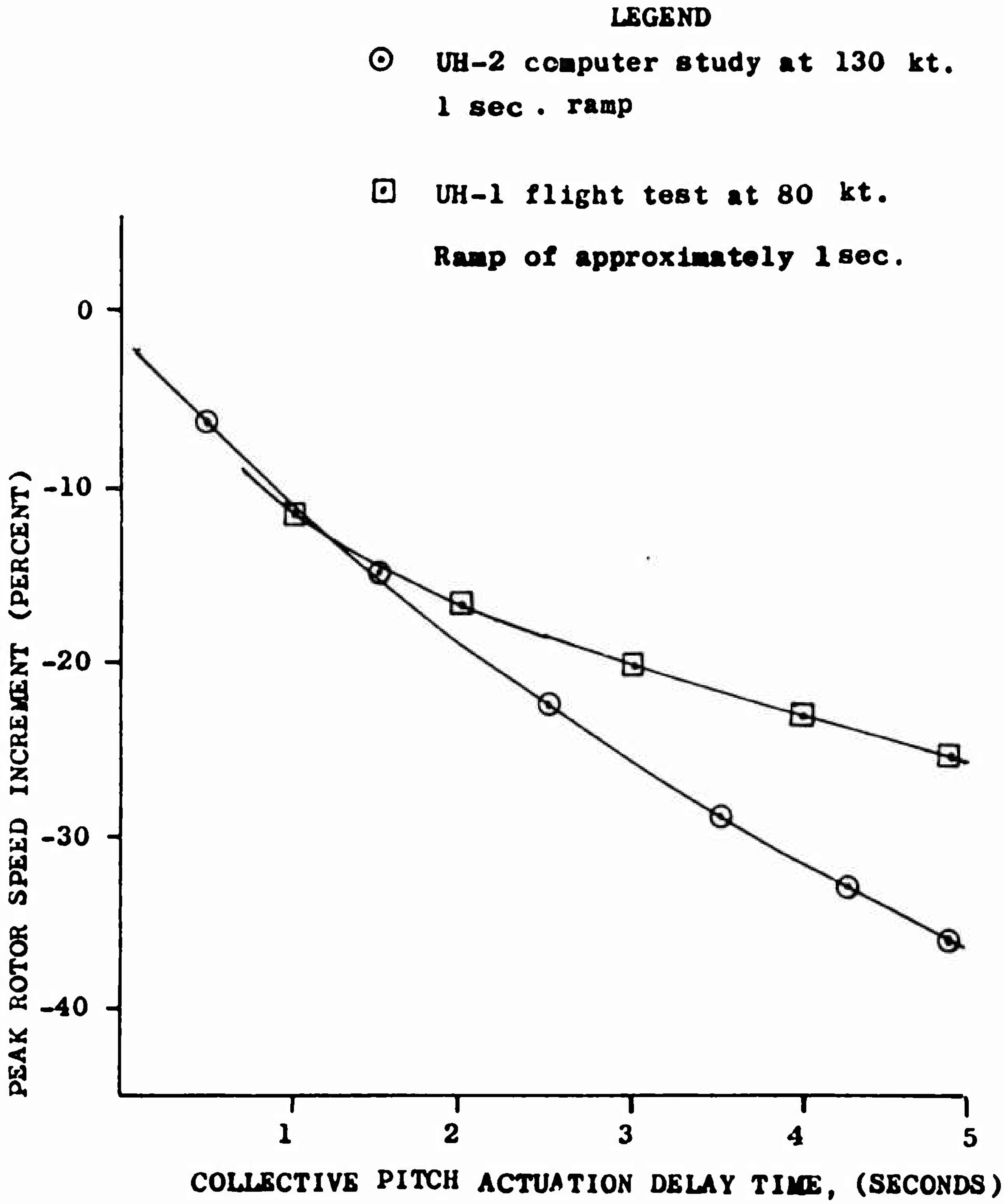


FIGURE 9. MAXIMUM TRANSIENT ROTOR SPEED INCREMENT AS A FUNCTION OF COLLECTIVE PITCH ACTUATION DELAY TIME.

The protective system requirement appears capable of reduction to an engine failure detection system to detect and indicate an engine failure within 1 second after the occurrence of the event.

ENGINE FAILURE DETECTION

The preceding sections have been aimed at demonstrating that the protective device requirement for single-turbine engine helicopters reduces to a detection and indication system only. Automatic actuation in response to failure detection is not required.

Prior to determination of the choice of engine failure detection means, it is necessary to clearly define what is meant by engine failure. For the purposes involved here, engine failure is, quite simply, a gross loss of power. This definition, therefore, excludes from consideration, latent failures (such as a nonmalignant turbine blade crack) or performance degradation failures. The exclusion of these (noncritical) failure modes is based on the fact that they present no requirement for immediate pilot responsiveness, but rather, a longer term effort (either by the pilot in flight, or by maintenance personnel on the ground).

There are two distinctly different methods for detecting a gross loss of engine power: power plant measurements, or helicopter measurements. Examples of power plant measurements are engine r.p.m., torque, or turbine inlet temperature; examples of helicopter measurements are normal acceleration, yawing acceleration (for single-rotor helicopters), or side acceleration.

While implicit sensing of engine failure is a logical possibility, it contains two inherent weaknesses. First, the measurement of helicopter parameters will contain more lag than the direct measurement of power plant parameters, since these measurements, by definition, are "after-the-fact". Second, a detection device based on implicit measurement would be more addicted to nuisance disturbances since the parameters involved can respond to disturbances other than engine failure. A normal acceleration device, for example, could be triggered by atmospheric turbulence. It is on the basis of these two principles that implicit measurement means are rejected.

Since explicit sensing of engine failure is desired, and since the detection requirement relates to gross loss of power, it is logical to examine the output variables first: rotor speed and torque. These parameters are direct indicators of engine output power.

The performance criteria for choosing between these two metnods include: accuracy, responsiveness, and reliability. Design considerations include: flexibility of application, size, weight and cost.

To gain insight into the performance characteristics of the two methods, Figure 10 may be examined. This is a time history of engine parameters during a simulated engine flameout of the T63-A-5 engine, furnished by the Allison Division of the General Motors Corporation.

Figure 10 shows that the changes in both torque and rotor or engine N_2 speed are pronounced following flameout. The time for each of these parameters to drop to 50 percent of initial value is: torque, 0.65 second and rotor speed, 1.10 seconds. However, the time for rotor speed to drop below governed range (that is, about 10 percent below initial speed) is only of the order of 0.4 second. This is an important point since it means that the N_2 response is actually sufficiently rapid, at least relative to the 1-second allowance described in the last section of this report.

Figure 11 shows a similar situation, but based on an actual in-flight throttle chop in a YH-40 helicopter. Here, the torque reduction is substantially more rapid than rotor speed droop. However, if the time required to fall below the lower limit of the normal rotor speed governed region (that is, about 10 percent less than initial N_2 speed) is examined, it may be noted that this occurs about 1 second following the throttle chop.

From the point of view of parameter unambiguity and response characteristics, the measurement of either of the two power plant output parameters is satisfactory, at least in the typical cases presented here. Figures 10 and 11 show that the torque response characteristic is considerably faster than the N_2 r.p.m. response, and that based on an allowance of 1 second for engine failure detection, the N_2 r.p.m. measurement is marginal. Despite the better responsiveness associated with torque sensing criterion, there are several fundamental disadvantages related to the use of the torque parameter for failure detection which are described in the following paragraphs.

1. Output torque, by itself, cannot actually be a measure of engine integrity. There are occasions when near-zero output torque is a satisfactory operating condition; for example, in practice autorotation maneuvers or during ground run-up. There are also occasions when very rapid torque reduction

is an intentional pilot maneuver; for example, to quickly enter the nap-of-the-earth to avoid enemy detection. These ambiguous conditions can be removed by relating output torque to collective pitch. This correlation is obtained by measurement of collective pitch position, and then calculating (by electronic simulation) the corresponding torque output. (A correction for density altitude might be required as well.) If this torque output differs substantially from the actual torque output (actual output much lower than required output) a failure situation is indicated. A system using this technique is shown in block diagram form in Figure 12; the complexity of this approach is immediately apparent.

2. The torque measurement is inherently nonlinear and in many implementations, not of great precision. The measurement generally has poorest accuracy and correlation in the low torque range where greatest accuracy would be desired for engine failure detection.

3. Output torque cannot be relied upon to indicate engine failure which might occur during autorotation maneuvers. While this is admittedly a circumstance of low probability, it is nevertheless poor practice to undertake the development of a protective device which is known in advance not to cover the entire operating range of the system which it is designed to protect.

4. There is no simple way to test the operability of the torque sensing system on the ground, prior to flight, except by simulation. This is a consequence of the fact that the system requires that the helicopter rotor be turning and loaded, as in flight. The possibility of loading the rotor with intermediate collective pitch settings, and then chopping the throttle, prior to takeoff, is very undesirable.

The fundamental disadvantages associated with torque output sensing, described above, makes it desirable to consider N_2 r.p.m. as the basic measurement parameter. N_2 r.p.m. can be used without correlation against any other parameter, is intrinsically a direct measurement of infinite precision (frequency measurement), will continue to monitor the power plant in autorotation maneuvers, and can be checked out on the ground simply and directly, without the necessity for engaging and loading the helicopter rotor.

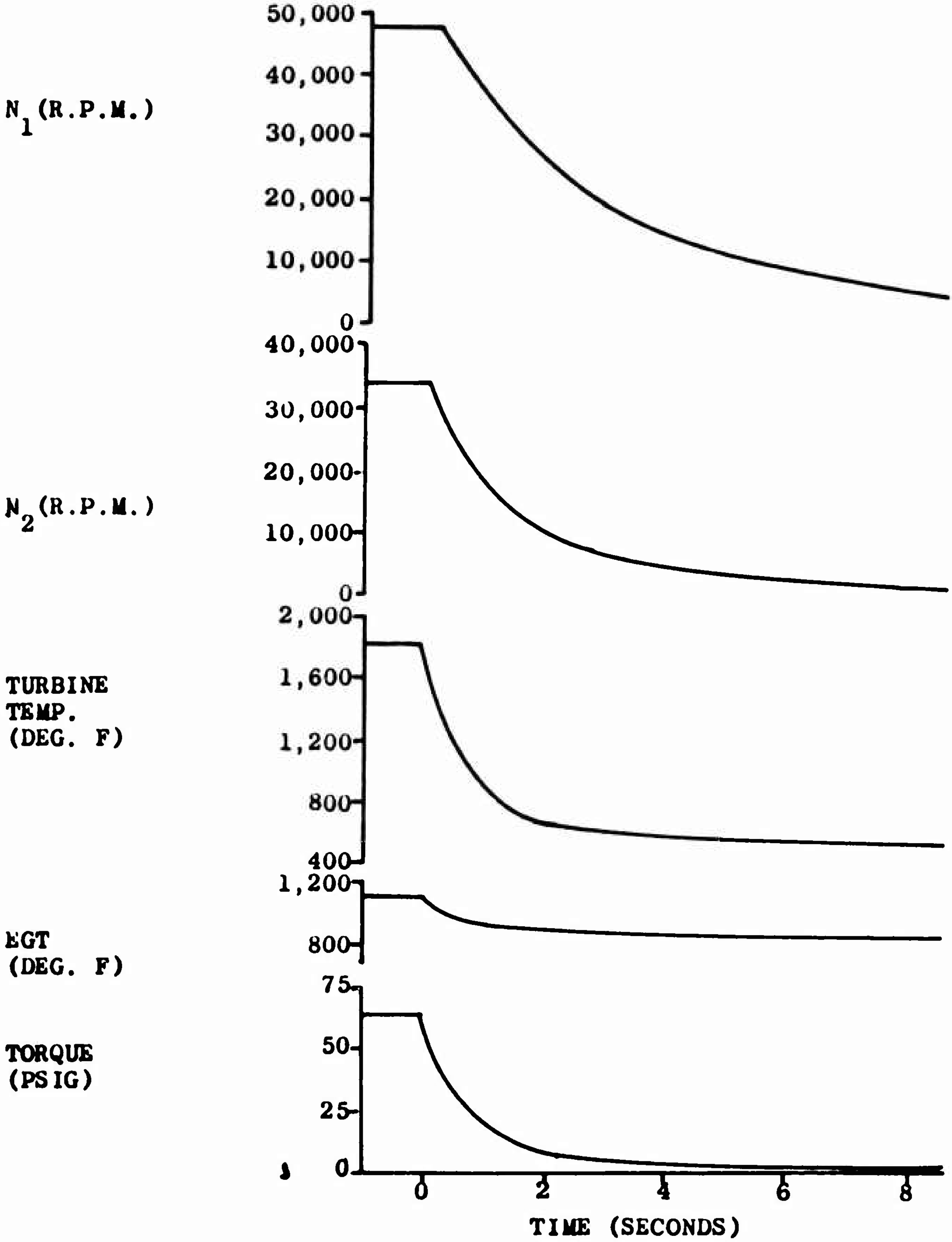


FIGURE 10. TIME HISTORY OF ENGINE PARAMETERS FOLLOWING THROTTLE CHOP - T63-A-5

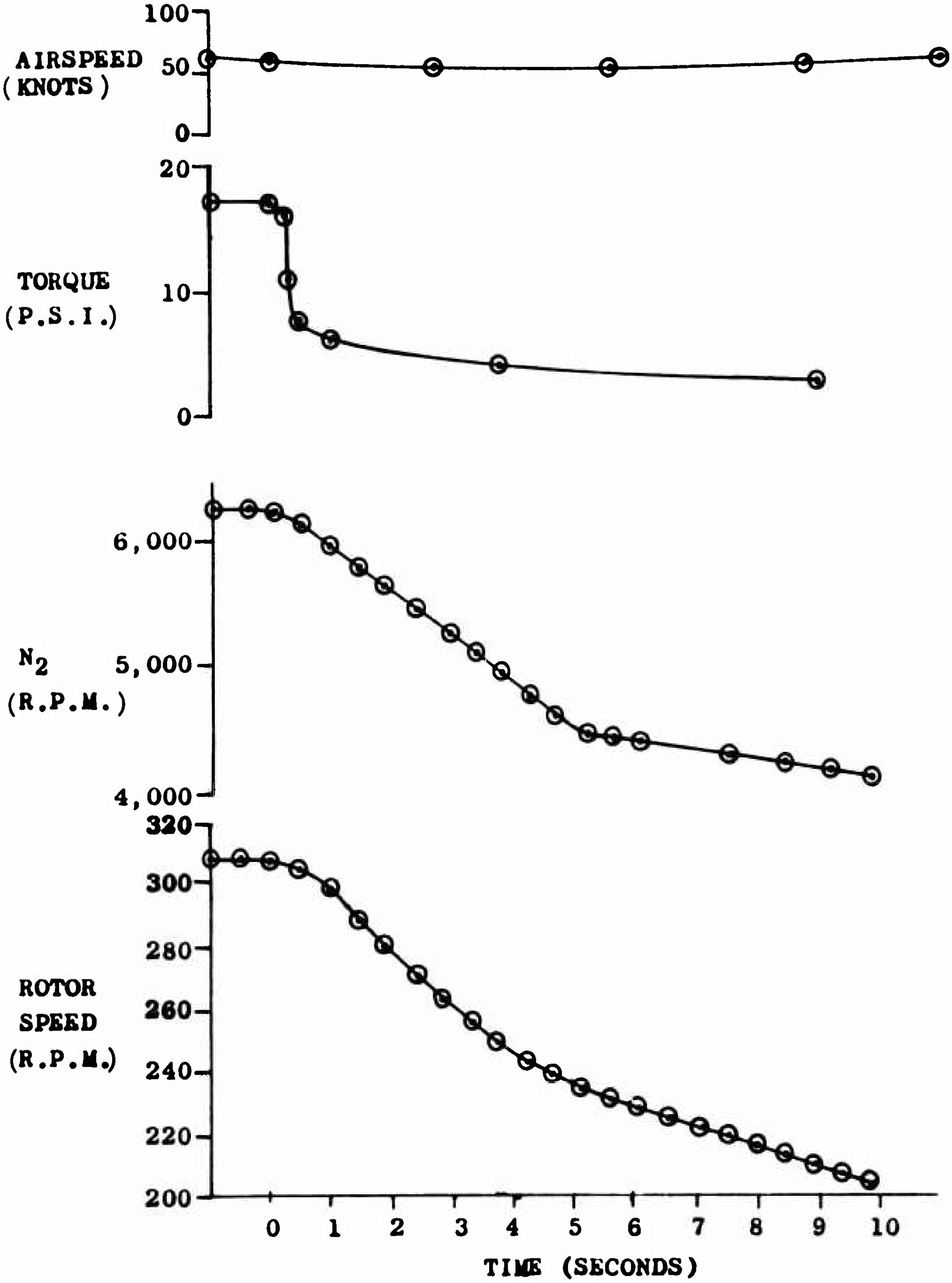


FIGURE 11. AIRCRAFT PARAMETERS FOLLOWING THROTTLE CHOP, (YH-40).

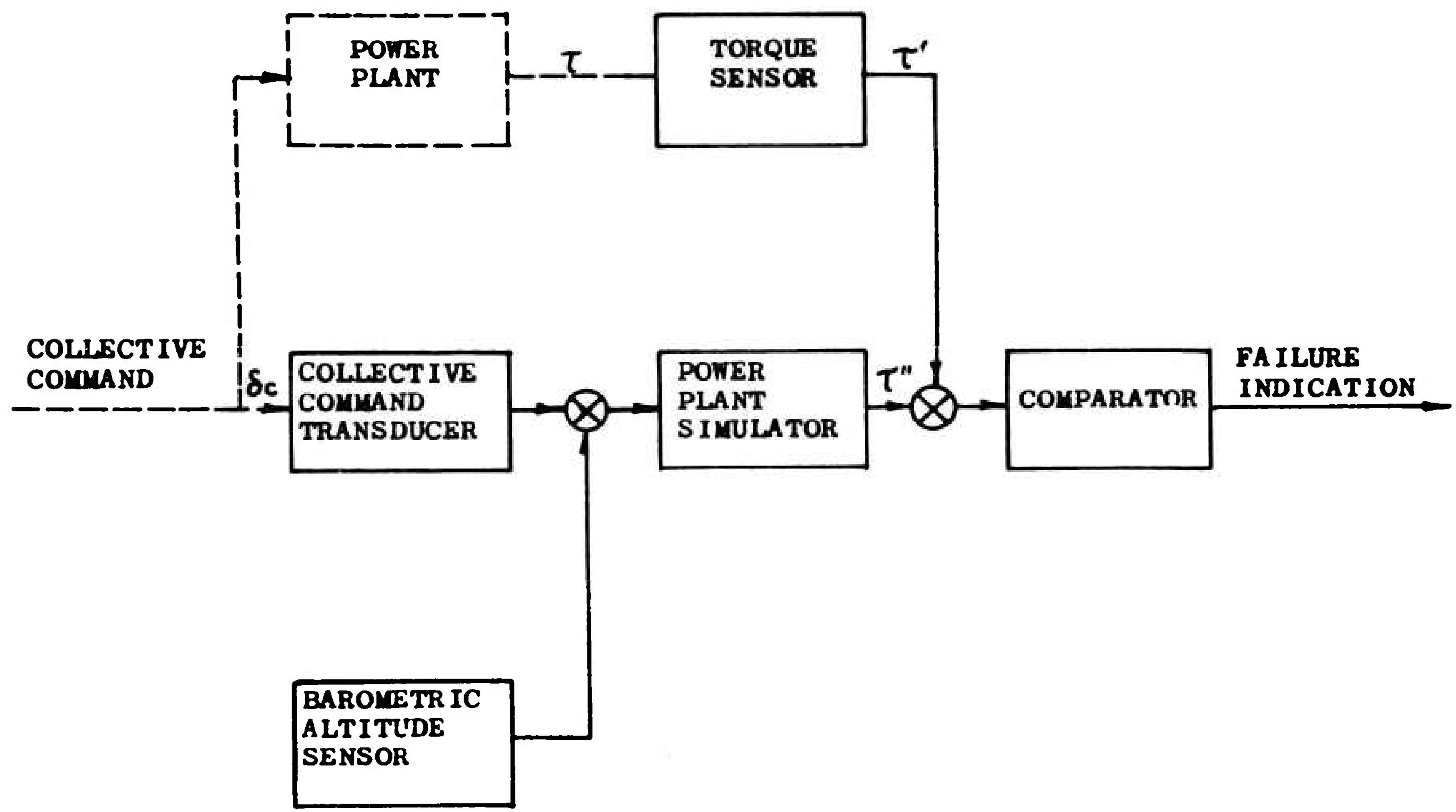


FIGURE 12. ENGINE FAILURE DETECTION TORQUE/COLLECTIVE APPROACH.

To make the use of N_2 r.p.m. completely advantageous, it is necessary to reduce the lags associated with this parameter, thereby making N_2 r.p.m. response as fast as torque response. This can be achieved by synthesizing a signal proportional to rate of change of N_2 r.p.m. As a first approximation (through resort to Newton's laws of mechanics) rate of change of N_2 r.p.m. is directly proportional to torque, at least in the very short time interval following the torque change. Aerodynamic torque on the rotor changes this relation somewhat, but the gross relation exists. Figure 11, for example, shows that the time required for the rate of change of r.p.m. to change from zero (prior to throttle chop) to a value of approximately 500 r.p.m. per second is well within 0.5 second. As such, this change is as rapid as the torque change illustrated in Figure 11.

For the N_2 r.p.m. rate system to work effectively, it is necessary that there be sufficient separation between the beep rates which can be commanded by the pilot and the rates which are symptomatic of engine failure. Also, the rates of change of r.p.m. associated with changes in rotor loading (due to turbulence, for example) must be somewhat less than those experienced in gross power plant failure. That this is normally the case in a well-governed helicopter is illustrated in Figure 13, which presents curves from an HH-43B tested in connection with a Lycoming T53-L-11 engine.* These curves are typical of similar maneuvers. Despite the rapid changes in collective pitch (about 30 percent transient in about 0.2 second) and despite the resulting abrupt maneuver (within the full acceleration limit of the aircraft), the change in N_2 r.p.m. is almost imperceptible.

A system approach using N_2 r.p.m. as the detection parameter is illustrated in Figure 14. A frequency transducer converts rotor tachometer frequency into an analogous d.c. voltage output. The output of the frequency transducer is compared against a stable voltage reference. The error difference between these two outputs is used as the input to a trigger amplifier, set to operate at the lower limit N_2 r.p.m. value selected for the helicopter to be protected. The purpose of this portion of the failure detection device is to protect against failures which result in relatively slow rate of change of N_2 r.p.m.

* W.F. Spurr, "Installation Test Results of the Lycoming T53-L-11 Engine in the HH-43B Helicopter", Kaman Aircraft Corporation Report No. T-353-3

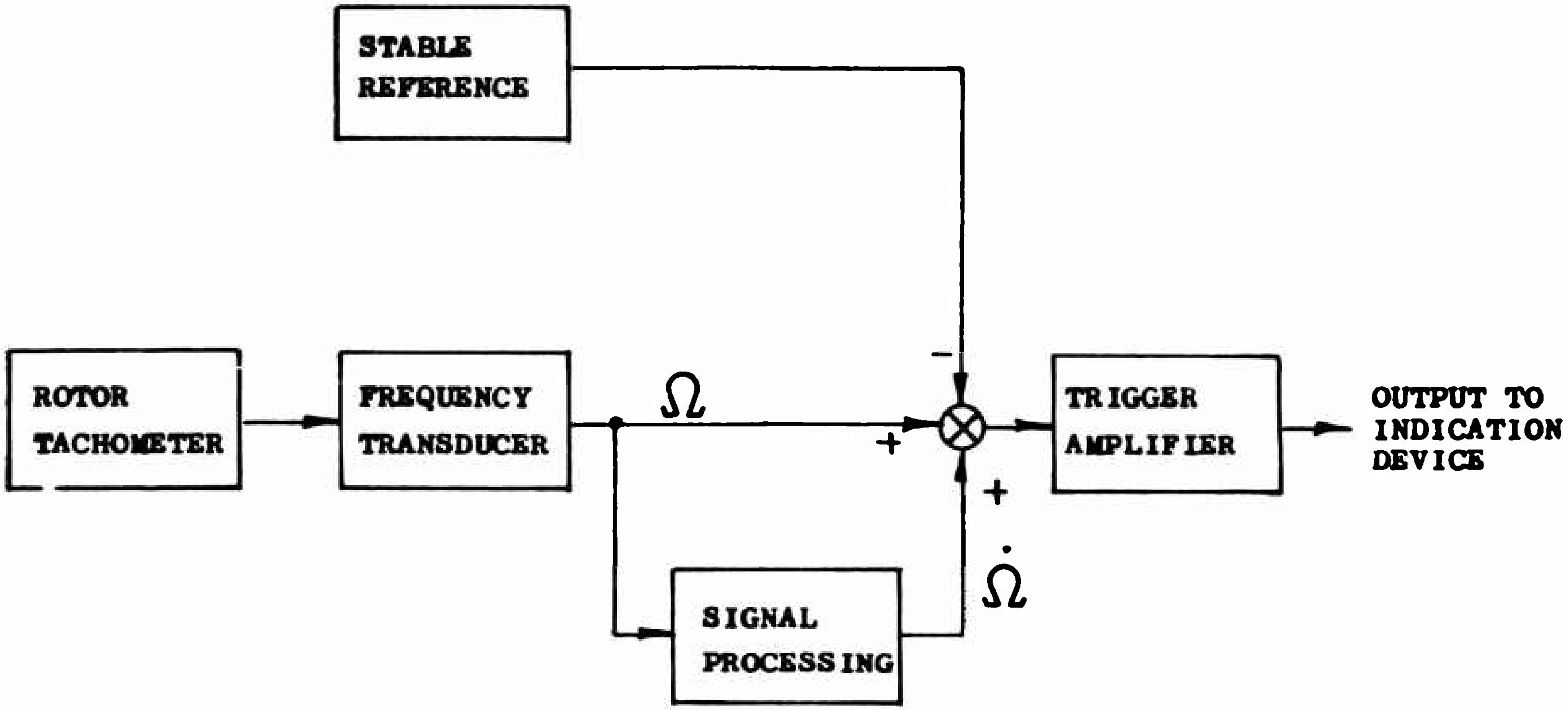


FIGURE 14. ENGINE FAILURE DETECTION, R.P.M. AND R.P.M. RATE APPROACH.

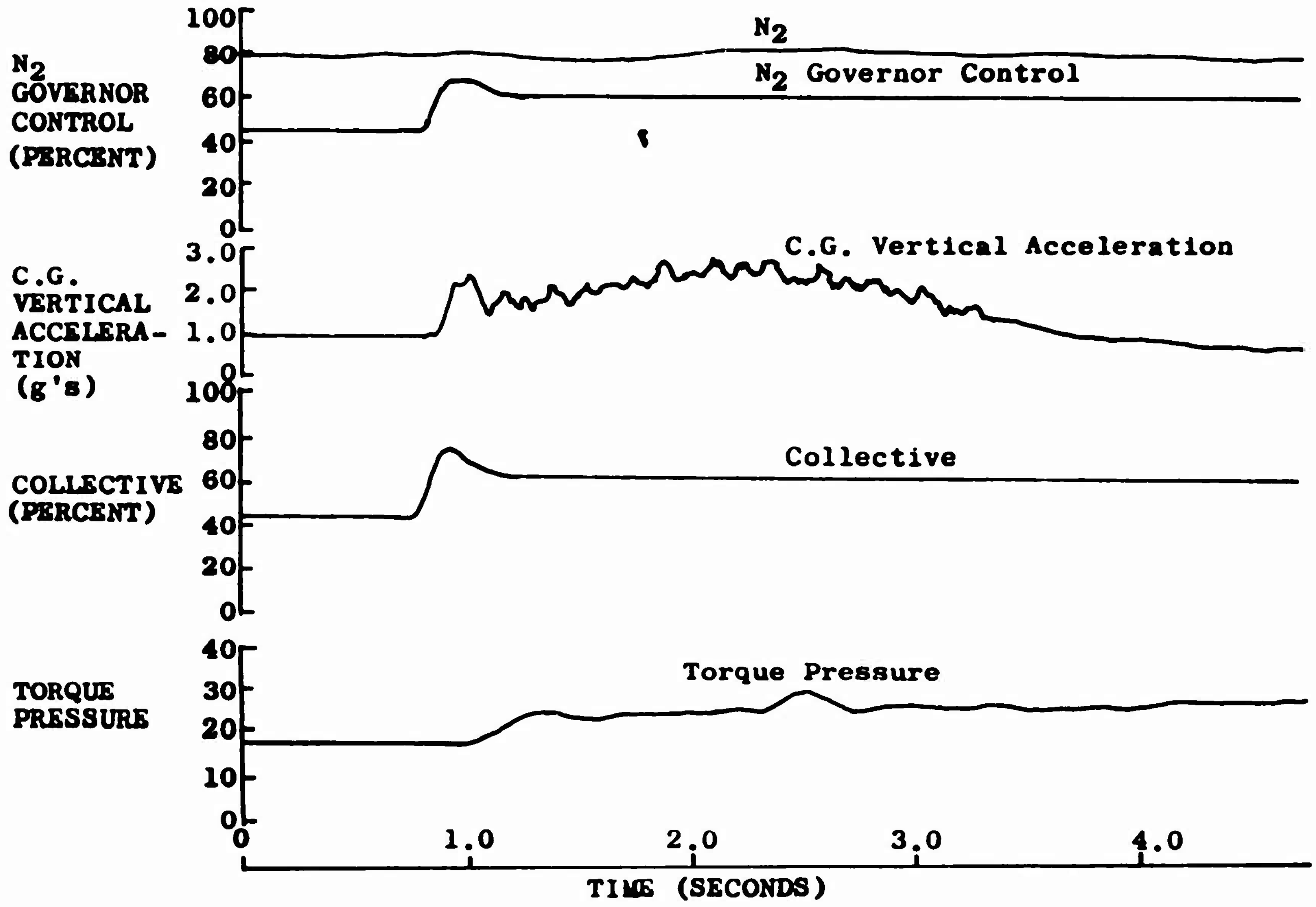


FIGURE 13. ABRUPT PULLOUT WITHIN g LIMITATION, HH-43B HELICOPTER.

For the more typical failures which are characterized by a rapid rate of change of N_2 r.p.m., the output of the frequency transducer is differentiated, and the differentiated (time rate) signal is used to trigger the failure indication output.

This system will, therefore, provide indication for any of the following conditions: low N_2 r.p.m., large rate of change of N_2 r.p.m., or combinations of the two.

To prevent nuisance triggering, it is desirable to incorporate a small lag in the output trigger amplifier. Inasmuch as a full second can be allowed for the failure indication to occur, the lag can be of the order of 0.5 second, since the basic lag in the parameter itself is of the order of 0.5 second. This filtering should be especially useful in discriminating against instantaneous, but brief, rotor decelerations which are occasioned by atmospheric turbulence.

Other advantages of the N_2 r.p.m. system should be indicated, in passing. Such a system can be designed to work universally in all helicopters, since it is based on the acceptance of a standardized signal; that is, N_2 tachometer output. (This may be contrasted with a torque output system whose characteristics, and design, would be based on the different methods of torque sensing used in various helicopters.) The operating signal is, itself, reliable and accurate. Finally, there are, already in existence, lightweight and low-cost r.p.m. warning systems which are essentially suitable for the function, lacking only in the availability of quickening.

To achieve high reliability, the system of Figure 14 allows for redundancy by using a majority voting technique. That this possibility can be entertained is a consequence of the simplicity of the system itself. The simple system permits redundancy to be achieved at a practical and economical level.

A block diagram of the redundant system is presented in Figure 15. The outputs of the three trigger amplifiers are fed to a switching logic system. The switches are connected so that operation of at least two of the three switches is required to produce a failure indication. This technique is used extensively in critical applications to permit single failures to occur without disabling the device. To ensure that failures do not go undetected for long periods of time, the logic system is arranged so that a minority indication (one out of three vote) is registered as a latched indication to be remedied by maintenance action.

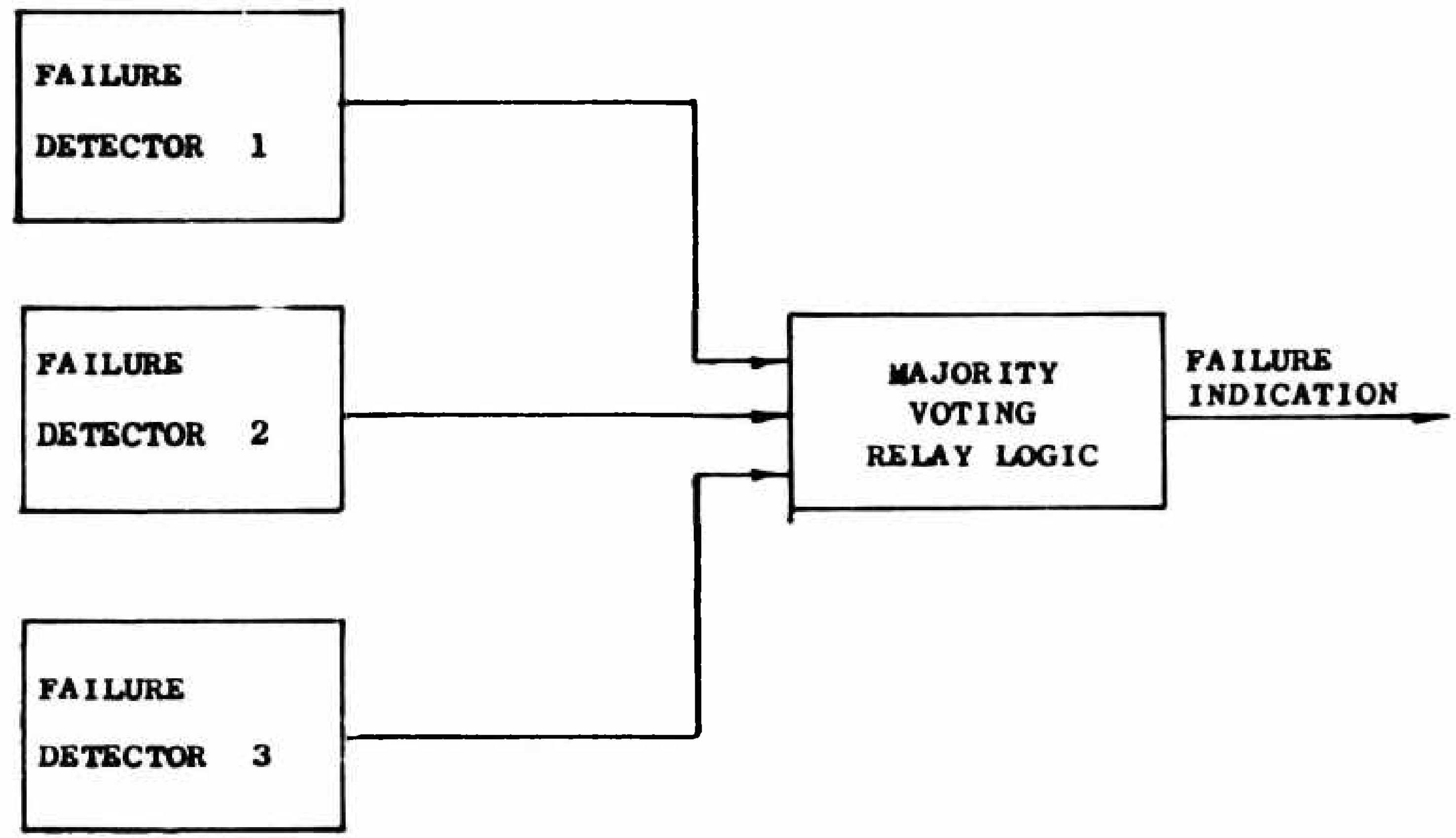


FIGURE 15. MAJORITY VOTING FAILURE DETECTOR SYSTEM.

Before proceeding to a discussion of indication techniques, the possibility of using more sophisticated sensing means should be mentioned. These would include temperature measurement (exhaust gas or turbine inlet), infrared detection, and a variety of other devices. None of these appear as simple, responsive and unambiguous as the N_2 measurement.

FAILURE INDICATION

The output of the failure detection device must be made to present a clear indication to the pilot. There are three self-evident indication media to choose from: visual, aural, and tactile.

The visual devices (lamps) are simple and straightforward. But, the warning stimulus is generated against the background of a complex panel containing other warning lights for other warning conditions. Furthermore, pilot attention is not always directed to the panel. Dependence upon visual stimulation, therefore, is doubtful as a general solution, although specific designs may be created which are quite acceptable.

Aural indication means include clackers, tones, verbal recordings, et cetera. The advantage of aural indication is that it does not require that pilot attention be directed inwardly to the helicopter. The aural cue chosen must be distinctive and different from other tones (including intercom system malfunction) that are occasionally present. A modulated tone (for example, normal tone frequency of the order of 500 cycles per second modulated at about 10 cycles per second) may furnish this characteristic. A steady tone could be too easily ignored.

A tactile indication device appears to offer great promise. The use of a stick shaker, as a direct carry-over from fixed wing stall warning systems is logical. It is not competitive with other warning stimuli (visual and aural). Problems associated with the use of stick shakers include solution to a relatively high ambient vibratory environment and accommodation of vibratory inputs to the control system.

Location of the stick shaker on the collective stick appears to be the most consistent from a human engineering point of view; that is, the control requiring attention is the one perturbed. Since it is conceivable that the collective stick may be occasionally unguarded, the installation of an additional shaker on the cyclic stick may be desirable.

The possibility of a redundant warning system, in which two or more different senses are stimulated, is worthy of consideration. Such a system would combine the advantages of each method of indication. Recent work on a so-called

"tickle-talk" system at Lockheed-Georgia* indicates that when other sense channels are information saturated, it is often possible to put in additional information by tactile means. Although there are many instances where aural or visual signals are ignored, researchers have yet to find a person who can ignore, for example, a strong electrical shock.

Of all of the continuing effort which could logically ensue from this program, the most obvious is an experimental study of warning indication media in helicopters. Such a study would not only furnish valuable background for the continued development of engine failure warning devices, but, more generally, warning devices of any kind.

* R. Levine, "Tickle Talk and Possible Flight Control Applications Utilizing Tactile Flight Communications", Presentation to the SAE Committee A-18, December 9, 1964

PILOT OPINION

A limited sampling of the opinion of six Army pilots to an engine failure protective system was made. Appendix III presents the responses of these pilots to the questions presented. The indications obtained from this sampling are that:

1. A warning device for turbine powered helicopters is necessary.

2. Automatic actuation of collective pitch (in response to an engine failure detection) is undesirable.

CONCLUSIONS

As a result of the studies and analyses conducted in this program, it is concluded that:

1. Projected Army tactical missions involve flight in two major categories: cruise (airspeed greater than 45 knots and altitude above 80 feet) and nap-of-the-earth. There is also flight exposure of significance at low airspeeds (below 45 knots) for altitudes over 10 feet. This combined exposure, in markedly different flight envelopes, requires a very complex programing of collective pitch following engine failure. The level of complexity precludes a practical automatic collective pitch control system. Therefore, it is concluded that an automatic collective pitch control system is impractical.

2. The dynamic response of the two typical helicopters studied here (UH-1 and UH-2) shows that there is ample time available for pilot-effected recovery, provided that a clear, unmistakable indication of power plant failure is presented within 1 second after the loss of power. Therefore, it is concluded that an automatic collective pitch control system is unnecessary.

3. The study covered here does show that a simple and reliable engine failure indication system is fundamentally desirable and feasible. Indications derived from a limited pilot opinion survey support the conclusions that a warning indicator is necessary, and that an automatic collective pitch feature is undesirable. This system should be based on r.p.m. as the basic parameter to be sensed and should contain "quickening" of the r.p.m. error to provide satisfactory responsiveness.

RECOMMENDATIONS

Studies of engine failure warning indication methods for helicopters should be undertaken, with the general objectives of determining the best design principles for indication of warning information.

BLANK PAGE

APPENDIX I

MISSION PROFILE ANALYSIS

The analysis of Army mission profiles has been carried out on the basis of data received from the Combat Development Agency Aviation Branch, Fort Rucker. A sample of these data is illustrated in Figure 16, which shows a typical light observation helicopter (LOH) mission.

To reduce these data to terms desired for the analysis of an engine failure protective warning system, the following procedure is used:

1. First, the mission is broken down into each significant stage.

2. For each stage of the mission, the time exposure in each of the four flight envelopes of Figure 1 is calculated.

3. The exposure in takeoff and landing is calculated on the basis of a conservative trajectory, indicated in Figure 2 and summarized in detail in Table 2. This trajectory is well within the longitudinal and vertical acceleration capability of current and projected Army helicopters.

4. Each mission is weighted, with the weighting factor selected on the basis of judgement. A weight of 3 is used for missions of anticipated great frequency. A weight of 2 is used for missions of high frequency. A weight of 1 is used for missions which occur at routine frequency.

5. The weighted average of exposure in the four flight envelopes is then calculated.

Step-by-step tabular summaries of the analysis of the LOH, UH-1B and UH-1D helicopters are contained in Tables 3, 4 and 5.

TABLE 2(a)

TAKEOFF/LANDING

PROFILE FOR FLIGHT INTO AREA III

Time Period (sec.) t_{n-1}	t_n	$\ddot{x}$ Average Forward Accelera-tion-g's (Note 1)*	Forward Velocity (ft./sec.) u_{n-1}	u_n (Note 2)*	$\ddot{z}$ Average Vertical Accelera-tion-g's (above 1g or below) (Note 3)*	Vertical Velocity (ft./sec.) W_{n-1}	W_n (Note 4)*	Altitude (ft.) h_{n-1}	h_n (Note 5)*	u_n (kt.)
0	10	0.1000	0	32.2	0.005	0	1.66	0	3.3	18.7
10	20	0.0800	32.2	57.6	0.005	1.66	3.22	3.3	27.7	33.6
20	30	0.0640	57.6	78.1	0.010	3.22	6.44	27.7	76.0	45.5
30	40	0.0512	78.1	94.5	0.010	6.44	9.66	76.0	152.0	55.0
40	50	0.0410	94.5	107.6	0	9.66	9.66	152.0	249.0	62.8
50	60	0.0328	107.6	118.2	0	9.66	9.66	249.0	346.0	69.0

* Notes applying to this table will be found on page 45.

LOH

VTOL
Payload - 3 man recon party - 720 lb.
Hover in Groud Effect - 6,000 ft. (Army hot day)
Hover Out of Ground Effect - 3,000 ft. (Army hot day)
Gross Weight - not to exceed 2,750 lb. (OH-13 gross weight)

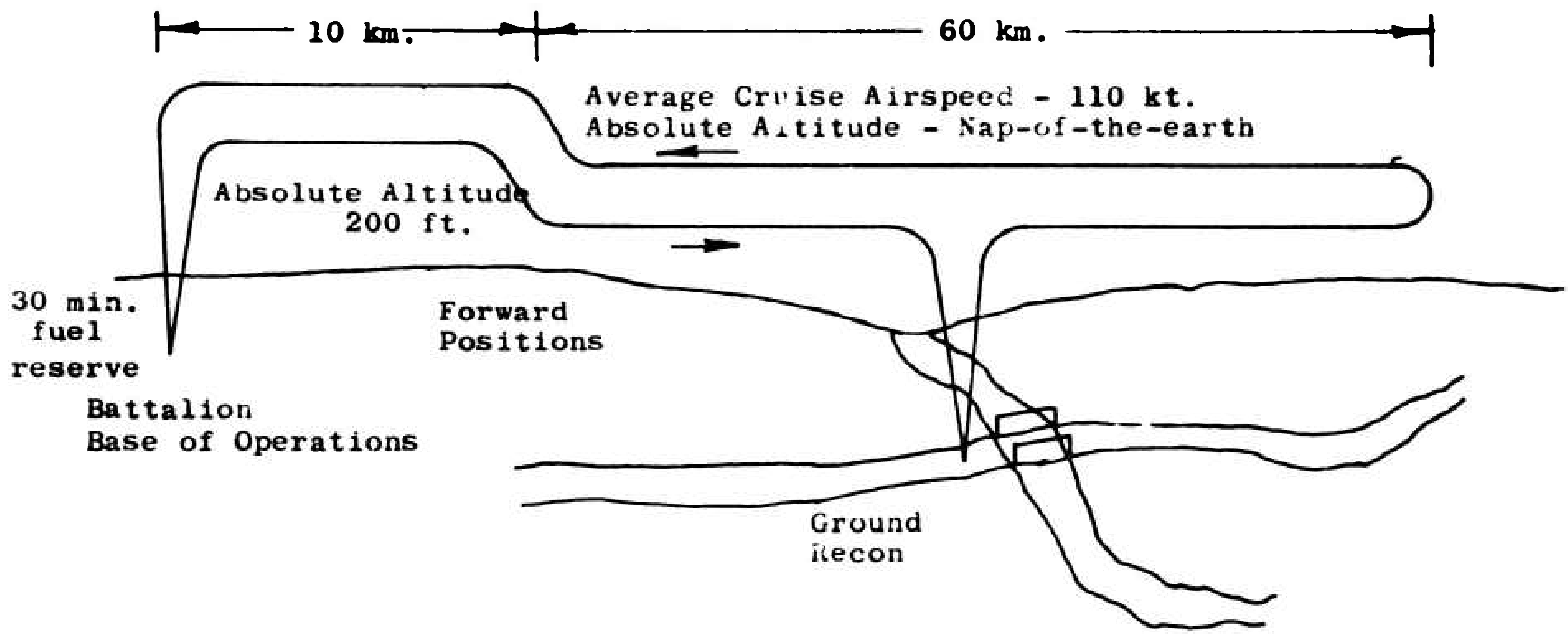


FIGURE 16. ROUTE RECONNAISSANCE.

TABLE 2(b)

TAKEOFF/LANDING

PROFILE FOR FLIGHT INTO AREA IV

Time Period (sec.) t_{n-1}	t_n	$\ddot{x}$ Average Forward Accelera-tion-g's (Note 1)*	Forward Velocity (ft./sec.) u_{n-1}	u_n (Note 2)*	$\ddot{z}$ Average Vertical Accelera-tion-g's (above 1g or below) (Note 3)*	Vertical Velocity (ft./sec.) W_{n-1}	W_n (Note 4)*	Altitude (ft.) h_{n-1}	h_n (Note 5)*	u_n (kt.)
0	10	0.1000	0	32.2	0.005	0	1.66	0	3.3	18.7
10	20	0.0800	32.2	57.6	0.005	1.66	3.22	3.3	27.7	33.6
20	30	0.0640	57.6	78.1	-0.008	3.22	0.64	27.7	47.0	45.5
30	40	0.0512	78.1	94.5	-0.002	0.64	0	47.0	50.3	55.0
40	50	0.0410	34.5	107.6	0	0	0	50.3	50.3	62.8
50	60	0.0328	107.6	118.2	0	0	0	50.3	50.3	69.0

* Notes applying to this table will be found on page 45.

NOTES FOR TABLES 2(a) AND 2(b)

Note 1: Average forward accelerations represent arbitrary assumptions. Initial acceleration of 0.10g. is attenuated by 20 percent every 10 seconds.

Note 2:

$$u_n = u_{n-1} + 32.2\left(t_n - t_{n-1}\right)\ddot{x}$$

but, $t_n - t_{n-1} = 10$ seconds

$$u_n = u_{n-1} + 322\ddot{x} \qquad (1)$$

Note 3: Average vertical acceleration represent arbitrary assumptions. Initial acceleration of 0.005g. is well within available thrust/weight ratio of current helicopters. Increase to 0.010g. reflects greater power available after developing translational lift.

Note 4:

$$W_n = W_{n-1} + 32.2\left(t_n - t_{n-1}\right)\ddot{z}$$

but, $t_n - t_{n-1} = 10$ seconds

$$W_n = W_{n-1} + 322\ddot{z} \qquad (2)$$

Note 5:

$$h_n = h_{n-1} + \left(\frac{W_{n-1} + W_n}{2}\right)\left(t_n - t_{n-1}\right)$$

but, $t_n - t_{n-1} = 10$ seconds

$$h_n = h_{n-1} + 5\left(W_{n-1} + W_n\right) \qquad (3)$$

TABLE 3(a)

MISSION PROFILE ANALYSIS

LOH

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
1. Route Reconnaissance				
Takeoff	.0031	.0052	-	-
Cruise 10 km/110 kt/ 200 ft.	-	-	.0487	-
Nap-of-the-earth 60 km/110 kt.				.2920
Landing - en route	.0031	.0052	-	-
Takeoff - en route	.0031	.0052	-	-
Nap-of-the-earth 60 km/110 kt. (return)	-	-	-	.2920
Cruise 10 km/110 kt/ 200 ft. (return)	-	-	.0487	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 0.71 hr.	.0124	.0208	.0974	.5840
2. Area Reconnaissance				
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-
Nap-of-the-earth 60 km/110 kt.	-	-	-	.2920
Area reconnaissance	-	-	-	1.5000
Nap-of-the-earth 60 km/110 kt. (return)	-	-	-	.2920
Cruise 20 km/110 kt/ 200 ft. (return)	-	-	.0974	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.30 hr.	.0062	.0104	.1950	2.0800
3. Visual Observation				
Takeoff	.0031	.0052	-	-

TABLE 3(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Cruise 30 km/110 kt/ 200 ft.	-	-	.1460	-
Loiter 2 hr.	-	-	.5000	1.5000
Cruise 30 km/110 kt/ 200 ft. (return)	-	-	.1460	
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.31 hr.	.0062	.0104	.7920	1.5000
4. Courier				
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 10 km/110 kt/ 200 ft.	-	-	.0487	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 10 km/110 kt/ 200 ft.	-	-	.0487	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 40 km/110 kt/ 200 ft. (return)	-	-	.1950	-
Land - complete mission	.0031	.0052	-	-
Total per trip	.0248	.0416	.3900	-
Six trips per mission - 2.74 hr.	.1490	.2500	2.3400	-
5. Radio Relay				
Takeoff	.0031	.0052	-	-
Cruise over area 60 kt/200 ft.	-	-	2.5000	-
Land - complete mission	.0031	.0052	-	-

TABLE 3(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Total - Mission 2.52 hr.	.0062	.0104	2.5000	-
6. Column Control				
Takeoff	.0031	.0052		
Cruise (0 to 110 kt)	-	.4000	.4000	-
Landing	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise (0 to 110 kt)	-	.4000	.4000	-
Landing	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise (0 to 110 kt)	-	.4000	.4000	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.45 hr.	.0186	1.2300	1.2000	-
7. Control of Maneuver Elements				
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-
Loiter	-	-	2.4000	-
Cruise 20 km/110 kt/ 200 ft. (return)	-	-	.0974	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.62 hr.	.0062	.0104	2.6000	-
8. Liaison				
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-
Cruise 20 km/110 kt/ 200 ft. (return)	-	-	.0974	-
Land - complete mission	.0031	.0052	-	-

TABLE 3(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Total per trip	.0062	.0104	.1950	-
Twelve trips per mission - 2.54 hr.	.0744	.1250	2.3400	-
9. Command and Staff Transportatio				
Takeoff	.0031	.0052	-	-
Cruise 10 km/110 kt/ 200 ft.	-	-	.0487	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 5 km/110 kt/ 200 ft.	-	-	.0244	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 5 km/110 kt/ 200 ft.	-	-	.0244	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 10 km/110 kt/ 200 ft.	-	-	.0487	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft. (return)	-	-	.0974	-
Land - complete mission	.0031	.0052	-	-
Total - Mission .327 hr.	.0310	.0520	.2440	-
10. Delivery of Critical Personnel or Supplies				
Takeoff	.0031	.0052	-	-
Cruise 10 km/110 kt/ 200 ft.	-	-	.0487	-
Cruise 10 km/110 kt/ 200 ft. (return)	-	-	.0487	-
Land - complete mission	.0031	.0052	-	-

TABLE 3(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Total per trip	.0062	.0104	.0974	-
Thirteen trips per mission - 1.49 hr.	.0806	.1350	1.2700	-
11. Dissemination of CW and BW Agents				
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-
Nap-of-the-earth 60 km/110 kt.	-	-	-	.2920
Loiter	-	-	-	.2500
Nap-of-the-earth 60 km/110 kt. (return)	-	-	-	.2920
Cruise 20 km/110 kt/ 200 ft. (return)	-	-	.0974	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 1.05 hr.	.0062	.0104	.1950	.8340
12. Map and Survey				
Takeoff	.0031	.0052	-	-
Cruise 30 km/110 kt/ 500 ft.	-	-	.1460	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 30 km/110 kt/ 500 ft.	-	-	.1460	-
Hover	-	1.0000	-	-
Cruise 30 km/110 kt/ 500 ft.	-	-	.1460	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 30 km/110 kt/ 500 ft.	-	-	.1460	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-

TABLE 3(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Cruise 120 km/110 kt/ 500 ft. (return)	-	-	.5840	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.24 hr.	.0248	1.0400	1.1700	-
13. Aerial Radiological Survey				
Takeoff	.0031	.0052	-	-
Cruise 15 km/110 kt/ 200 ft.	-	-	.0730	-
Survey 53 kt/200 ft.	-	-	2.3000	-
Cruise 15 km/110 kt/ 200 ft. (return)	-	-	.0730	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.47 hr.	.0062	.0104	2.4500	-
14. Electronic Warfare				
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-
Nap-of-the-earth 10 km/110 kt.	-	-	-	.0487
Operations 53 kt/200 ft.	-	-	2.3000	-
Nap-of-the-earth 10 km/110 kt. (return)	-	-	-	.0487
Cruise 20 km/110 kt/ 200 ft. (return)	-	-	.0974	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.60 hr.	.0062	.0104	2.4900	.0974

TABLE 3(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
15. Armed Escort and Defensive Air-to-Air Destruction				
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-
Nap-of-the-earth 60 km/110 kt.	-	-	-	.2920
Operations	-	-	-	1.7000
Nap-of-the-earth 60 km/110 kt. (return)	-	-	-	.2920
Cruise 20 km/110 kt/ 200 ft. (return)	-	-	.0974	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.49 hr.	.0062	.0104	.1950	2.2800
16. Armed Reconnaissance				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 65 km/110 kt.	-	-	-	.3160
Operations	-	-	-	2.0000
Nap-of-the-earth 65 km/110 kt. (return)	-	-	-	.3160
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.65 hr.	.0062	.0104	-	2.6300
17. Security Between Units				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 5 km/0-110 kt.	-	.2000	.0120	-
Operations	-	.4000	-	2.1000
Nap-of-the-earth 5 km/0-110 kt. (return)	-	.2000	.0120	-
Land - complete mission	.0031	.0052	-	-

TABLE 3(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Total - Mission 2.94 hr.	.0062	.8100	.0240	2.1000
18. Rear Area Security				
Takeoff	.0031	.0052	-	-
Cruise 10 km/0-110 kt.	-	.2000	.0240	-
Operations	-	.4000	-	2.1000
Cruise 10 km/0-110kt. (return)	-	.2000	.0240	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.96 hr.	.0062	.8100	.0480	2.1000
19. Advance Guard				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 5 km/0-110 kt.	-	.2000	.0120	-
Operations	-	.4000	-	2.1000
Nap-of-the-earth 5 km/0-110 kt. (return)	-	.2000	.0120	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.94 hr.	.0062	.8100	.0240	2.1000
20. Flank Guard				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 5 km/0-110 kt.	-	.2000	.0120	-
Operations	-	.4000	-	2.1000
Nap-of-the-earth 5 km/0-110 kt. (return)	-	.2000	.0120	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.94 hr.	.0062	.8100	.0240	2.1000

TABLE 3(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
21. Rear Guard				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 5 km/0-110 kt.	-	.2000	.0120	-
Operations	-	.4000	-	2.1000
Nap-of-the-earth 5 km/0-110 kt. (return)	-	.2000	.0120	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.94 hr.	.0062	.8100	.0240	2.1000
22. Screening (Covering Force)				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 25 km/0-110 kt.	-	.0900	.0974	-
Operations	-	.5000	-	1.5000
Nap-of-the-earth 25 km/0-110 kt. (return)	-	.0900	.0974	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.39 hr.	.0062	.6900	.1950	1.5000
23. Screening (Flank or Rear)				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 25 km/0-110 kt.	-	.0900	.0974	-
Operations	-	.5000	-	1.5000
Nap-of-the-earth 25 km/0-110 kt. (return)	-	.0900	.0974	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.39 hr.	.0062	.6900	.1950	1.5000

TABLE 3(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
24. Aerial Dispersion of Chemical Agents in Riot Control				
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-
Dispersion 40-50 kt/ 75-100 ft.	-	.0600	-	-
Cruise 20 km/110 kt/ 200 ft. (return)	-	-	.0974	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 0.27 hr.	.0062	.0704	.1950	-
25. Search and Rescue				
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-
Nap-of-the-earth 10 km/110 kt.	-	-	-	.0487
Search	-	-	.5000	1.5000
Nap-of-the-earth 10 km/110 kt. (return)	-	-	-	.0487
Cruise 20 km/110 kt/ 200 ft. (return)	-	-	.0974	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.31 hr.	.0062	.0104	.6950	1.6000
26. Medical Evacuation				
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 20 km/110 kt/ 200 ft.	-	-	.0974	-

TABLE 3(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 40 km/110 kt/ 200 ft. (return)	-	-	.1950	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 0.45 hr.	.0186	.0312	.3900	-
27. Ferry				
Takeoff	.0031	.0052	-	-
Cruise 1130 km/110 kt/ 5000 ft.	-	-	5.5500	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 5.56 hr.	.0062	.0104	5.5500	-

TABLE 3(b)

MISSION PROFILE ANALYSIS

LOH

SUMMARY

Mission	Weighting Factor	Total Time (Hr.)	Area I	Area II	Area III	Area IV
Route Reconnaissance	3	.710	.012	.021	.097	.584
Area Reconnaissance	1	2.300	.006	.010	.195	2.080
Visual Observation	2	2.310	.006	.010	.792	1.500
Courier	2	2.740	.149	.250	2.340	-
Radio Relay	1	2.520	.006	.010	2.500	-
Column Control	1	2.450	.019	1.230	1.200	-
Control of Maneuver Elements	1	2.620	.006	.010	2.600	-
Liaison	2	2.540	.074	.125	2.340	-
Command and Staff Transportation	3	.327	.031	.050	.244	-
Delivery of Critical Personnel or Supplies	3	1.490	.081	.135	1.270	-
Dissemination of CW and BW Agents	1	1.050	.006	.010	.195	.834
Map and Survey	1	2.240	.025	1.040	1.170	-
Aerial Radiological Survey	1	2.470	.006	.010	2.450	-
Electronic Warfare	1	2.600	.006	.010	2.490	.097
Armed Escort and Defensive Air-to-Air Destruction	1	2.490	.006	.010	.195	2.280
Armed Reconnaissance	1	2.650	.006	.010	-	2.630
Security Between Units	1	2.940	.006	.810	.024	2.100
Rear Area Security	1	2.960	.006	.810	.048	2.100

TABLE 3(c)

WEIGHTING OF MISSIONS

LOH

No. of Missions	Weighting Factor	Total Time (Hr.)	Area I	Area II	Area III	Area IV
3	3	2.48	.124	.206	1.560	.584
Average		.83	.041	.069	.520	.191
Area Product		2.48	.124	.206	1.560	.584
4	2	7.45	.248	.416	5.270	1.500
Average		1.86	.062	.104	1.320	.375
Area Product		3.72	.124	.208	2.640	.750
20	1	51.00	.152	7.870	20.C00	23.000
Average		2.55	.008	.393	1.000	1.150
Area Product		2.55	.008	.393	1.000	1.150
Area Products (Total)		8.75	.256	.807	5.200	2.490
Weighted Average		1.46	.043	.135	.866	.415
Resultant Time Apportionment		100.00	2.900	9.300	59.800	28.000

TABLE 3(b) (Cont'd.)

Mission	Weighting Factor	Total Time (Hr.)	Area I	Area II	Area III	Area IV
Advance Guard	1	2.940	.006	.810	.024	2.100
Flank Guard	1	2.940	.006	.810	.024	2.100
Rear Guard	1	2.940	.006	.810	.024	2.100
Screening (Covering Force)	1	2.390	.006	.690	.195	1.500
Screening (Flank or Rear)	1	2.390	.006	.690	.195	1.500
Aerial Dispersion of Chemical Agents in Riot Control	1	.270	.006	.070	.195	-
Search and Rescue	1	2.310	.006	.010	.695	1.600
Medical Evacuation	2	.450	.019	.031	.390	-
Ferry	1	5.560	.006	.010	5.550	-

TABLE 4(a)

MISSION PROFILE ANALYSIS

UH-1B

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
1. Armed Escort and Defensive Air-to-Air Destruction				
Takeoff	.0031	.0052	-	-
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Nap-of-the-earth 20 km/100 kt.	-	-	-	.108
Loiter	-	-	-	.170
Nap-of-the-earth 20 km/100 kt.	-	-	-	.1C8
Dashes	-	-	-	.170
Nap-of-the-earth 20 km/100 kt.	-	-	-	.108
Cover for Landing Force	-	-	-	.750
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.08 hr.	.0062	.0104	.324	1.738
2. Armed Reconnaissance				
Takeoff	.0031	.0052	-	-
Cruise 5 km/100 kt/ 200 ft.	-	-	.027	-
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324
Target Area	-	-	-	1.400
3 landings	.0093	.0156	-	-
3 takeoffs	.0093	.0156	-	-
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324

TABLE 4(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Cruise 5 km/100 kt/ 200 ft.	-	-	.027	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.17 hr.	.0248	.0416	.054	2.048
3. Complement and Extend Ground Fires (On Call)				
Takeoff	.0031	.0052	-	-
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324
On target	-	-	-	.167
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 1.16 hr.	.0062	.0104	.324	.815
4. Complement and Extend Ground Fires (On Station)				
Takeoff	.0031	.0052	-	-
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324
On target	-	-	-	.167
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324
On station	-	-	1.000	-
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Land - complete mission	.0031	.0052	-	-

TABLE 4(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Total - Mission 2.16 hr.	.0062	.0104	1.324	.815
5. Close-In Protection of Forward Element (On Call)				
Takeoff	.0031	.0052	-	-
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
On target	-	-	1.000	-
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 1.34 hr.	.0062	.0104	1.324	-
6. Close-In Protection of Forward Elements (On Station)				
Takeoff	.0031	.0052	-	-
Cruise 15 km/100 kt/ 200 ft.	-	-	.081	-
On station	-	-	1.800	-
Cruise 15 km/100 kt/ 200 ft.	-	-	.081	-
On target	-	-	.300	-
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.44 hr.	.0062	.0104	2.424	-
7. Rear Area Security				
Takeoff	.0031	.0052		
Cruise 10 km/70 kt/ 200 ft.	-	-	.077	-
Air cover 70 kt.	-	-	2.000	-

TABLE 4(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Cruise 10 km/70 kt/ 200 ft.	-	-	.077	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.17 hr.	.0062	.0104	2.154	-
8. Security Between Units				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 5 km/70 kt.	-	-	-	.038
Forward Observation 70 kt.	-	-	.500	1.500
Nap-of-the-earth 5 km/70 kt.	-	-	-	.038
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.09 hr.	.0062	.0104	.500	1.576
9. Advance Guard				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 5 km/70 kt.	-	-	-	.038
Air guard	-	-	-	2.000
Nap-of-the-earth 5 km/70 kt.	-	-	-	.038
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.09 hr.	.0062	.0104	-	2.076
10. Flank Guard (2 Aircraft)				
Takeoff	.0062	.0104	-	-
Nap-of-the-earth 5 km/70 kt.	-	-	-	.076
Air guard	-	-	-	4.000
Nap-of-the-earth 5 km/70 kt.	-	-	-	.076

TABLE 4(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Land - complete mission	.0062	.0104	-	-
Total - Mission 4.18 hr.	.0124	.0208	-	4.152
11. Rear Guard				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 5 km/70 kt.	-	-	-	.038
Air guard	-	-	-	2.000
Nap-of-the-earth 5 km/70 kt.	-	-	-	.038
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.09 hr.	.0062	.0104	-	2.076
12. Screening (Covering Force)				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 25 km/70 kt.	-	-	-	.190
Air cover	-	-	-	1.900
Nap-of-the-earth 25 km/70 kt.	-	-	-	.190
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.3 hr.	.0062	.0104	-	2.280
13. Screening (Flank or Rear)				
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 25 km/70 kt.	-	-	-	.190
Air cover	-	-	-	1.900
Nap-of-the-earth 25 km/70 kt.	-	-	-	.190

TABLE 4(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.3 hr.	.0062	.0104	-	2.280
14. Medical Evacuation				
Takeoff	.0031	.0052	-	-
Cruise 18 km/100 kt/ 200 ft.	-	-	.097	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 15 km/100 kt/ 200 ft.	-	-	.081	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 33 km/100 kt/ 200 ft.	-	-	.178	-
Land - complete mission	.0031	.0052	-	-
Total - Mission .406 hr.	.0186	.0312	.356	-
15. Ferry				
Takeoff	.0031	.0052	-	-
Cruise 1,370 km/100 kt/ 6,000 ft.	-	-	7.400	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 7.42 hr.	.0062	.0104	7.400	

TABLE 4(c)

WEIGHTING OF MISSIONS

UH-1B

Number of Missions	Weighting Factor	Total Time (Hr.)	Area I	Area II	Area III	Area IV
0	3	-	-	-	-	-
Average		-	-	-	-	-
Area Product		-	-	-	-	-
2	2	4.60	.012	.021	-	4.56
Average		2.30	.006	.010	-	2.28
Area Product		4.60	.012	.021	-	4.56
13	1	31.79	.118	.197	16.19	15.29
Average		2.44	.009	.015	1.24	1.18
Area Product		2.44	.009	.015	1.24	1.18
Area Product (Total)		7.04	.021	.036	1.24	5.74
Weighted Average		2.34	.007	.012	.41	1.91
Resultant Time Apportionment		100.00	.300	.500	17.60	81.60

TABLE 4(b)

MISSION PROFILE ANALYSIS

UH-1B

SUMMARY

Mission	Weighting Factor	Total Time (Hr.)	Area I	Area II	Area III	Area IV
Armed Escort and Defensive Air-to-Air Destruction	1	2.080	.0062	.0104	.324	1.738
Armed Reconnaissance	1	2.170	.0248	.0416	.054	2.048
Complement and Extend Ground Fires (On Call)	1	1.160	.0062	.0104	.324	.815
Complement and Extend Ground Fires (On Station)	1	2.160	.0062	.0104	1.324	.815
Close-In Protection of Forward Element (On Call)	1	1.340	.0062	.0104	1.324	-
Close-In Protection of Forward Elements (On Station)	1	2.440	.0062	.0104	2.424	-
Rear Area Security	1	2.170	.0062	.0104	2.154	-
Security Between Units	1	2.090	.0062	.0104	.500	1.576
Advance Guard	1	2.090	.0062	.0104	-	2.076
Flank Guard (Two Aircraft)	1	4.180	.0124	.0208	-	4.152
Rear Guard	1	2.090	.0062	.0104	-	2.076
Screening (Covering Force)	2	2.300	.0062	.0104	-	2.280
Screening (Flank or Rear)	2	2.300	.0062	.0104	-	2.280
Medical Evacuation	1	.406	.0186	.0312	.356	-
Ferry	1	7.420	.0062	.0104	7.400	-

TABLE 5(a)

MISSION PROFILE ANALYSIS

UH-1D

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
1. Route Reconnaissance				
Takeoff	.0031	.0052	-	-
Cruise 10 km/100 kt/ 200 ft.	-	-	.054	-
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324
2 Landings - en route	.0062	.0104	-	-
2 Takeoffs - en route	.0062	.0104	-	-
Nap-of-the-earth 60 km/100 kt. (return)	-	-	-	.324
Cruise 10 km/100 kt/ 200 ft. (return)	-	-	.054	-
Land - complete mission	.0031	.0052	-	-
Total - Mission .81 hr.	.0186	.0310	.108	.648
2. Area Reconnaissance				
Takeoff	.0031	.0052	-	-
Cruise 30 km/100 kt/ 200 ft.	-	-	.160	-
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324
Area reconnaissance	-	-	-	1.500
Nap-of-the-earth 60 km/100 kt. (return)	-	-	-	.324
Cruise 30 km/100 kt/ 200 ft. (return)	-	-	.160	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.48 hr.	.0062	.0104	.320	2.148
3. Visual Observation				
Takeoff	.0031	.0052	-	-

TABLE 5(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Cruise 30 km/100 kt/ 200 ft.	-	-	.160	-
Loiter 2.6 hr.	-	-	.800	1.800
Cruise 30 km/100 kt/ 200 ft. (return)	-	-	.160	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.94 hr.	.0062	.0104	1.120	1.800
4. Command and Staff Transportation				
Takeoff	.0031	.0052	-	-
Cruise 15 km/100 kt/ 200 ft.	-	-	.081	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 10 km/100 kt/ 200 ft.	-	-	.054	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 10 km/100 kt/ 200 ft.	-	-	.054	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 15 km/100 kt/ 200 ft.	-	-	.081	-
2 Landings	.0062	.0104	-	-
2 Takeoffs	.0062	.0104	-	-
Cruise 20 km/100 kt/ 200 ft. (along front)	-	-	.108	-
Cruise 50 km/100 kt/ 200 ft. (return)	-	-	.270	-
Land - complete mission	.0031	.0052	-	-
Total - Mission .748 hr.	.0372	.0624	.648	-

TABLE 5(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
5. Radio Relay				
Takeoff	.0031	.0052	-	-
Cruise 60 kt/200 ft.	-	-	3.000	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 3.02 hr.	.0062	.0104	3.000	-
6. Aerial Command Post				
Takeoff	.0031	.0052		
Cruise over base 0-100 kt/200 ft.	-	-	1.500	1.500
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 3.03 hr.	.0124	.0208	1.500	1.500
7. Tactical Airlift (Landing)				
Takeoff	.0031	.0052		
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Nap-of-the-earth 60 km/100 kt.	-	-	-	.324
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 1.01 hr.	.0124	.0208	.324	.648

TABLE 5(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
8. Tactical Airlift (Air Drop)				
Takeoff	.0031	.0052	-	-
Cruise 90 km/100 kt/ 200-400 ft.	-	-	.480	-
On station 400 ft.	-	-	.250	-
Cruise 90 km/100 kt/ 200-400 ft. (return)	-	-	.480	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 1.23 hr.	.0062	.0104	1.210	-
9. Logistical Airlift				
Takeoff	.0031	.0052	-	-
Cruise 40 km/100 kt/ 200 ft.	-	-	.216	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 40 km/100 kt/ 200 ft. (return)	-	-	.216	-
Land - complete mission	.0031	.0052	-	-
Total - Mission .46 hr.	.0124	.0208	.432	-
10. Dissemination of CW and BW Agents				
Takeoff	.0031	.0052	-	-
Cruise 20 km/100 kt/ 200 ft.	-	-	.108	-
Nap-of-the-earth 60 km.	-	-	-	.324
Target area, nap-of-the-earth	-	-	-	.250
Nap-of-the-earth 60 km.	-	-	-	.324
Cruise 20 km/100 kt/ 200 ft.	-	-	.108	-

TABLE 5(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Land - complete mission	.0031	.0052	-	-
Total - Mission 1.13 hr.	.0062	.0104	.216	.898
11. Map and Survey				
Takeoff	.0031	.0052	-	-
Cruise 30 km/100 kt/ 500 ft.	-	-	.160	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 30 km/100 kt/ 500 ft.	-	-	.160	-
Hover	-	1.0000	-	-
Cruise 30 km/100 kt/ 500 ft.	-	-	.160	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 30 km/100 kt/ 500 ft.	-	-	.160	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 120 km/100 kt/ 500 ft. (return)	-	-	.640	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.35 hr.	.0248	1.0400	1.280	-
12. Electronic Warfare				
Takeoff	.0031	.0052	-	-
Cruise 20 km/100 kt/ 200 ft.	-	-	.108	-
Nap-of-the-earth 10 km/100 kt.	-	-	-	.054
Operations 53kt/200 ft.	-	-	2.600	-
Nap-of-the-earth 10 km/100 kt. (return)	-	-	-	.054

TABLE 5(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Cruise 20 km/100 kt/ 200 ft. (return)	-	-	.108	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.94 hr.	.0062	.0104	2.816	.108
13. Illumination				
Takeoff	.0031	.0052	-	-
Cruise 20 km/100 kt/ 200 ft.	-	-	.108	-
Climb 20 km/60 kt/ 4,000 ft.	-	-	.180	-
On station 60 kt/ 4,000 ft.	-	-	2.300	-
Descend 20 km/60 kt.	-	-	.180	-
Cruise 20 km/100 kt/ 200 ft.	-	-	.108	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.9 hr.	.0062	.0104	2.876	-
14. Search and Rescue				
Takeoff	.0031	.0052	-	-
Cruise 20 km/100 kt/ 200 ft.	-	-	.108	-
Nap-of-the-earth 10 km/100 kt.	-	-	-	.054
Search	-	-	.800	1.800
Nap-of-the-earth 10 km/100 kt. (return)	-	-	-	.054
Cruise 20 km/100 kt/ 200 ft. (return)	-	-	.108	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.9 hr.	.0062	.0104	1.016	1.908

TABLE 5(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
15. Propaganda Dissemination				
Takeoff	.0031	.0052	-	-
Cruise 30 km/100 kt/ 200 ft.	-	-	.162	-
Nap-of-the-earth	-	-	-	2.600
Cruise 30 km/100 kt/ 200 ft. (return)	-	-	.162	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 2.94 hr.	.0062	.0104	.324	2.600
16. Wire Laying				
Takeoff	.0031	.0052	-	-
Cruise 7 km/100 kt/ 200 ft.	-	-	.038	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Wire laying, nap-of-the-earth 50 kt.	-	-	-	.010
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 8 km/100 kt/ 200 ft.	-	-	.043	-
Land - complete mission	.0031	.0052	-	-
Total - Mission .14 hr.	.0186	.0312	.081	.010
17. Medical Evacuation (Division)				
Takeoff	.0031	.0052	-	-
Cruise 8 km/100 kt/ 200 ft.	-	-	.043	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 7 km/100 kt/ 200 ft.	-	-	.038	-

TABLE 5(a) (Cont'd.)

Mission and Events	Time (Hr.) Spent In Area I	Area II	Area III	Area IV
Land - complete mission	.0031	.0052	-	-
Total per trip .11 Seventeen trips per mission 1.87 hr.	.0124	.0208	.081	
18. Medical Evacuation (Field Army)				
Takeoff	.0031	.0052	-	-
Cruise 37 km/100 kt/ 200 ft.	-	-	.200	-
Land	.0031	.0052	-	-
Takeoff	.0031	.0052	-	-
Cruise 37 km/100 kt/ 200 ft.	-	-	.200	-
Land - complete mission	.0031	.0052	-	-
Total per trip .43 Seven trips per mission 3.03 hr.	.0124	.0208	.400	-
19. Ferry				
Takeoff	.0031	.0052	-	-
Cruise 1500 km/100 kt/ 8,000 ft.	-	-	8.100	-
Land - complete mission	.0031	.0052	-	-
Total - Mission 8.12 hr.	.0062	.0104	8.100	-

TABLE 5(c)

WEIGHTING OF MISSIONS

UH-1D

Number of Missions	Weighting Factor	Total Time (Hr.)	Area I	Area II	Area III	Area IV
2	3	3.790	.049	.083	2.148	1.500
Average		1.890	.025	.042	1.074	.750
Area Product		5.670	.075	.126	3.222	2.250
1	2	2.940	.006	.010	1.120	1.800
Average		2.940	.006	.010	1.120	1.800
Area Product		5.880	.012	.020	2.240	3.600
16	1	37.290	.440	1.730	26.480	8.980
Average		2.330	.027	.108	1.650	.560
Area Product		2.330	.027	.108	1.650	.560
Area Product (Total)		13.880	.110	.254	7.110	6.430
Weighted Average		2.310	.020	.040	1.190	1.070
Resultant Time Apportionment		100.000	.800	1.900	51.000	46.300

TABLE 5(b)

MISSION PROFILE ANALYSIS

UH-1D

SUMMARY

Mission	Weighting Factor	Total Time (Hr.)	Area I	Area II	Area III	Area IV
Route Reconnaissance	1	.810	.018	.031	.108	.648
Area Reconnaissance	1	2.480	.006	.010	.320	2.148
Visual Observation	2	2.940	.006	.010	1.120	1.800
Command and Staff Transportation	3	.748	.037	.062	.648	-
Radio Relay	1	3.020	.006	.010	3.000	-
Aerial Command Post	3	3.030	.012	.021	1.500	1.500
Tactical Airlift (Landing)	1	1.010	.012	.021	.324	.648
Tactical Airlift (Air Drop)	1	1.230	.006	.010	1.210	-
Logistical Airlift	1	.460	.012	.021	.432	-
Dissemination of CW and BW Agents	1	1.130	.006	.010	.216	.898
Map and Survey	1	2.350	.025	1.040	1.280	-
Electronic Warfare	1	2.940	.006	.010	2.816	.108
Illumination	1	2.900	.006	.010	2.876	-
Search and Rescue	1	2.900	.006	.010	1.016	1.908
Propaganda Dissemination	1	2.940	.006	.010	.324	2.600
Wire Laying	1	.140	.019	.031	.081	.010
Medical Evacuation (Division) 17 trips per mission	1	1.870	.211	.354	1.380	-
Medical Evacuation (Field Army) 7 trips per mission	1	3.030	.087	.146	2.800	-
Ferry	1	8.120	.006	.010	8.100	-

APPENDIX II

UH-2 DYNAMIC ANALYSIS

The equations of motion are derived in an earth-oriented axis system and represent accelerated flight equilibrium in the horizontal and vertical directions and about the pitch axis. In addition, the rotor speed equation is included as a fourth degree of freedom. The equations take the form:

$$m\dot{U} = F_{x_U}\Delta U + F_{x_q}q + F_{x_\theta}\Delta\theta + F_{x_w}\Delta w + F_{x_\Omega}\Delta\Omega + F_{x_{\delta_0}}\Delta\delta_0 + F_{x_{\delta_1}}\Delta\delta_1 \quad (4)$$

$$m\dot{w} = F_{z_U}\Delta U + F_{z_q}q + F_{z_\theta}\Delta\theta + F_{z_w}\Delta w + F_{z_\Omega}\Delta\Omega + F_{z_{\delta_0}}\Delta\delta_0 + F_{z_{\delta_1}}\Delta\delta_1 \quad (5)$$

$$I_y\dot{q} = M_U\Delta U + M_q q + M_\theta\Delta\theta + M_w\Delta w + M_\Omega\Delta\Omega + M_{\delta_0}\Delta\delta_0 + M_{\delta_1}\Delta\delta_1 \quad (6)$$

$$I_s\dot{\Omega} = -Q_E(1 - e^{-t/\tau}) - Q_U\Delta U - Q_q q - Q_\theta\Delta\theta - Q_w\Delta w - Q_\Omega\Delta\Omega$$

$$- Q_{\delta_0}\Delta\delta_0 - Q_{\delta_1}\Delta\delta_1 \quad (7)$$

The first term on the right-hand side of the rotor speed equation represents an exponential decay of rotor torque at engine failure.

TABLE 6

HELICOPTER CONSTANTS AND DERIVATIVE VALUES AT HOVER AND 130 KNOTS

Derivative	Hover	Speed (130 kt.)	Dimension
F_{x_u}	-6.00	21.40	lb/ft/sec.
F_{x_q}	425.00	698.00	lb/rad/sec.
F_{x_θ}	-7,560.00	-1,790.00	lb/rad.
F_{x_w}	-	26.40	lb/ft/sec.
F_{x_Ω}	-	50.10	lb/rad/sec.
$F_{x_{\delta_0}}$	-	-10,100.00	lb/rad.
$F_{x_{\delta_1}}$	11,200.00	705.00	lb/rad.
F_{z_u}	-	39.20	lb/ft/sec.
F_{z_q}	51.60	-1,920.00	lb/rad/sec.
F_{z_θ}	-	-434,000.00	lb/rad.
F_{z_w}	-78.20	-196.00	lb/ft/sec.
F_{z_Ω}	-520.00	-501.00	lb/rad/sec.
$F_{z_{\delta_0}}$	87,900.00	120,000.00	lb/rad.
$F_{z_{\delta_1}}$	-	65,500.00	lb/rad.
M_u	88.70	81.00	ft/lb/ft/sec.
M_q	-13,100.00	-19,600.00	ft/lb/rad/sec.
M_θ	-	-36,800.00	ft/lb/rad.
M_w	-	-168.00	ft/lb/ft/sec.
M_Ω	-	-3.38	ft/lb/rad/sec.
M_{δ_0}	-12,100.00	-124,000.00	ft/lb/rad.
M_{δ_1}	-206,000.00	-214,000.00	ft/lb/rad.
Q_E	13,300.00	14,600.00	ft/lb.
Q_u	-	-596.00	ft/lb/ft/sec.
Q_q	-	13,700.00	ft/lb/rad/sec.
Q_θ	-	4,100.00	ft/lb/rad.
Q_w	-13.00	26.00	ft/lb/ft/sec.
Q_Ω	9,160.00	9,760.00	ft/lb/rad/sec.
Q_{δ_0}	-150,000.00	-121,000.00	ft/lb/rad.
Q_{δ_1}	-	-33,300.00	ft/lb/rad.
m	235.00	235.00	slugs
I_y	13,500.00	13,500.00	slug ft^2
I_s	4,320.00	4,320.00	slug ft^2
τ	.26	.26	sec.
Ω	29.10	29.10	rad/sec.

APPENDIX III

PILOT OPINION SAMPLING

1. Q: Would you consider an engine failure warning device valuable, or necessary, or not required, in helicopters?

   A: I consider a turbine engine warning device necessary in helicopters. The turbine engine runs relatively quietly and the pilot normally would have difficulty realizing that he was experiencing an emergency that required immediate attention. This is vividly demonstrated during tactical gunnery training missions. The mission requires nap-of-the-earth flying technique and the aviator's primary concern requires his attention outside of the cockpit. Even with a warning, the aviator would be hard pressed to take appropriate action to recover under the best of circumstances. His nap-of-the-earth altitude would be to his disadvantage.

   A: Necessary in turbine helicopters.

   A: Warning device, yes! Preferably audio. This should be for low r.p.m. only.

   A: An audio/visual warning device that shows the pilot an engine is or has failed is desirable. However, the system should be in the warning mode only. It should not be designed to take any control away from the pilot.

   A: Turbine - necessary. Piston - desirable.

   A: Very valuable due to the same noise level at 5,000 r.p.m. to 6,600 r.p.m.

2. Q: Upon engine failure detection while flying in a flight region where autorotation was the acceptable recovery technique for the pilot, would you consider an automatic collective pitch control valuable, or necessary, or not required?

A: I would consider an automatic down collective pitch control on turbine-powered helicopters to be of questionable value. Without more information on how it operates, how much it weighs, how it would be turned on and off, how many and from where are the sensings obtained, et cetera, no worthwhile opinion could be given. Offhand, however, it seems doubtful if any experienced pilot wants anything other than his own left hand operating his collective pitch control - especially during critical operations.

A: Valuable. I would prefer a cyclic shaker in conjunction with visual and audio as exists in the Bell system on UH-1B.

A: Not necessary - not required. I feel that this would be a dangerous device as you often do not lower collective when experiencing a failure; that is, hover, high hover, or maximum takeoff.

A: A system which can give an audio or visual or both warning that an engine or section of an engine has failed is quite desirable. However, any system which would take the collective pitch control away from the pilot is considered as a hazard to flight.

A: Not required.

A: No - not necessary.

BLANK PAGE

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Kaman Aircraft Corp., Electronic Systems Div. Old Windsor Road Bloomfield, Connecticut	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
A STUDY OF REQUIREMENTS FOR ENGINE FAILURE PROTECTIVE WARNING SYSTEMS IN SINGLE-ENGINE TURBINE HELICOPTERS.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final report

5. AUTHOR(S) (Last name, first name, initial)
Kaufman, Lawrence A.
Van Train, James L.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1965	81	4

8a. CONTRACT OR GRANT NO. DA 44-177-AMC-155 (T)	9a. ORIGINATOR'S REPORT NUMBER(S) USAAVLABS Technical Report 65-55
b. PROJECT NO. c. Task 1P121401A14178 d.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) Kaman Report No. R-565

10. AVAILABILITY/LIMITATION NOTICES
Qualified requesters may obtain copies of this report from DDC.
This report has been furnished to the Department of Commerce for sale to the public.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY US Army Aviation Materiel Laboratories Fort Eustis, Virginia

13. ABSTRACT

The final report is presented of a study program intended to evaluate recovery techniques associated with loss of power in single engine helicopters throughout the flight envelopes currently attainable in actual Army missions. The report includes detailed mission profile analyses, helicopter dynamic analysis, and considerations of system design factors. It is concluded that redundant warning of power plant failures is feasible and desirable but that automatic actuation following failure is impractical and unnecessary.

14 KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Gas turbine engine Single engine helicopter Engine failure detection Engine failure warning Automatic collective pitch Helicopter recovery techniques Helicopter flight envelopes						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (*TS*), (*S*), (*C*), or (*U*).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.